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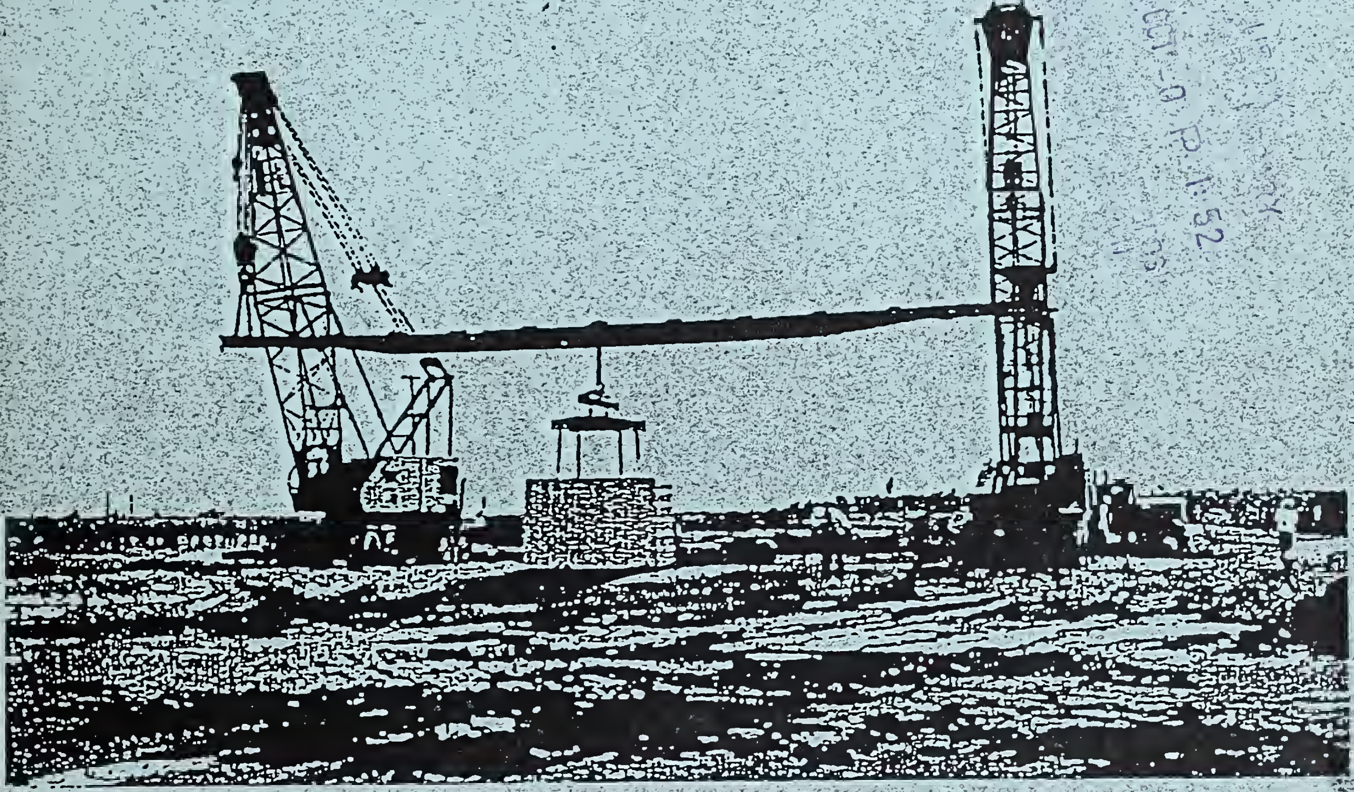

WATER MANAGEMENT RESEARCH LABORATORY

PROGRESS REPORT 1993

ANNUAL PROGRESS REPORT

1993

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TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

TITLE PAGE

TABLE OF CONTENTS (CONT'D)

INTRODUCTION

The Water Management Research Laboratory Research Progress Report is intended to inform upper level management within the Agricultural Research Service, other ARS research locations involved in natural resources research, and our many collaborators and cooperators about progress made on our research projects in 1993 and plans for 1994. It is our intent to keep the individual reports short but informative, focusing on objectives, approaches, summarized results and future plans for the project.

The overall mission of the Water Management Research Laboratory is to conduct research and to develop advanced water management practices, methods, equipment, and systems to utilize soil, water, nutrients, and energy resources efficiently and to improve sustainability and crop productivity in irrigated agriculture under water-limited conditions.

The Laboratory, in cooperation with personnel at the U.S. Salinity Lab in Riverside, CA, the U.S. Cotton Research Station at Shafter, CA, and the University of California, Riverside and Davis, CA, has initiated several research projects addressing specifically the issues of the impact of limited water supplies and drainage on water quality, water use efficiency, sustainability and productivity of Western irrigated agriculture and alternative crops and cropping systems for bioremediation of impacted soils. Cooperative projects are funded by the California Department of Water Resources (DWR) and the State Water Resource Control Board, the Imperial Irrigation District (IID, the Metropolitan Water District (MWD) of Southern California and the Imperial Valley Conservation Research Center Committee (IVCRCC), Pima Grow, and Vicksburg Chemical.

We invite you to use this annual report and to forward your questions and comments to us at your convenience; they will be appreciated. We thank you for your support and interest.

James E. Ayars

JAMES E. AYARS
Acting Research Leader

MANAGEMENT RESEARCH LABORATORY STAFF

I. Federal Employees

1. Scientists

Name	Position
Phene, Claude	Research Leader, Soil Sci.
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Hutmacher, Robert	Plant Physiologist
Banuelos, Gary	Plant/Soil Scientist
Avishalom Marani	Visiting Scientist, Israel
Ioan Paltineanu	Visiting Scientist, Romania
Mohammad Rehan	Visiting Scientist, Egypt

2. Technical Support/Full Time

Name	Position
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Dale, Frank	Hydrologic Technician
Davis, Kenneth	Soil Scientist
Dettinger, David	Machinist
Mead, Richard	Soil Scientist
Pflaum, Tom	Chemist
Schoneman, Richard	Agricultural Engineer
Vail, Sue	Biological Technician, Plants
Zambrzuski, Stella	Biological Technician, Plants

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Name	Position
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MANAGEMENT RESEARCH LABORATORY STAFF

3. Administrative Support

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Paula Lynch	Secretary

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Herrera, Nick	Research Apprentice	J. Ayars
Hinds, Fay	Laboratory Technician	B. Hutmacher
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Litman, Vanessa	Reseach Apprentice	G. Bañuelos
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WATER QUALITY MANAGEMENT ON WESTSIDE OF SAN JOAQUIN VALLEY-BRITZ PROJECT WATER BALANCE

R.A. Schoneman, J.E. Ayars, M. Beta, and F. Dale

OBJECTIVE: Monitor applied irrigation water, rainfall, soil moisture changes, and evapotranspiration to estimate contributions from groundwater in each Subsurface drip irrigated (SDI) and surface irrigated plot.

PROCEDURES: Water applications for each plot were metered and totalled for the season. The furrows in the surface irrigated plots were blocked to prevent runoff. The surface irrigated plots were scheduled by ranch management. SDI cotton irrigations were scheduled using a crop coefficient adjusted to account for groundwater contributions. Seasonal rainfall was from CIMIS data at a station 6 miles from the project site. Soil moisture was monitored through the season by neutron probe. Evapotranspiration (Et_c) was calculated using pan evaporation, a pan coefficient, and a basal crop coefficient. Biomass samples were also taken so a total dry matter estimate of Et could be calculated for cotton, using an equation developed by WMRL staff (Davis, 1983).

RESULTS: Surface irrigated tomatoes received four distinct irrigations, then were irrigated continuously for three more cycles across the field. Irrigation occurred from May 5 to July 14. Surface irrigated cotton received three seasonal applications from June 13 to August 27. SDI irrigation of tomatoes began and ended on virtually the same dates as the surface irrigated plots. SDI irrigation of cotton began a week and a half earlier than the surface irrigated plots and ended two days earlier. Table 1 lists seasonal applied water, effective rainfall (events over 6 mm), soil moisture change, Et_c, and Et estimated from biomass in millimeters, and groundwater contribution in percent. Et_c values suggest that the SDI plots used groundwater from 33-47% of total Et for cotton. Moreover, the plots that showed losses to deep percolation were restricted to surface furrow-irrigated plots. Using Et estimated from biomass, groundwater contributions were higher which would indicate that the basal coefficient did not sufficiently account for all crop water use. Modifications to the basal coefficient have been covered in another report in this publication. Applied water for the SDI cotton plots was 33 mm (1.3") less than the surface irrigated plot and the SDI tomato plots showed an 86 mm (3.4") savings over the surface irrigated plots. The ranch appears to recognize the value of reducing irrigation inputs in the field planted to cotton as indicated by the smaller discrepancy in the application amounts between systems and the lack of deep percolation. However, it is evident some additional savings exist for the field planted to tomatoes, since deep percolation was indicated in those plots.

FUTURE PLANS: These data will be included in a manuscript.

UNITS ARE MM.							
PLOT [1]	APPLIED WATER a	EFFECTIVE RAIN b	SOIL MOISTURE DEPLETION [2] c	Etc d	Et EST. FROM BIOMASS g	GROUND-WATER PERCENT [3] e	GW% FROM BIOMASS [3] f
DCF	335	0	14	578	645	40	46
DT1	211	0	17	578	593	61	62
DT2	340	0	23	578	823	37	56
DT3	366	0	24	578	750	33	48
DT4	307	0	20	578	657	43	50
DT5	292	0	16	578	630	47	51
DT6	503	21	2	567		7	
DT7	498	21	5	567		8	
DT8	472	21	10	567		11	
DT9	465	21	9	567		13	
DT10	470	21	8	567		12	
VCF	472	21	11	567		11	
NCO	610	21	-3	567		-11	
NCO/F	668	21	-2	567		-21	
NCF	521	21	4	567		4	

[1] PLOTS LABELED "DT" REFER TO SDI PLOTS - ALL OTHER PLOTS ARE SURFACE-IRRIGATED (FURROW).

[2] NEGATIVE NUMBERS INDICATE A SEASONAL INCREASE IN SOIL MOISTURE WHILE POSITIVE NUMBERS INDICATE A SEASONAL DECREASE IN SOIL MOISTURE.

[3] NEGATIVE NUMBERS INDICATE LOSSES TO DEEP PERCOLATION. POSITIVE NUMBERS INDICATE CROP USE OF THE GROUNDWATER. GROUNDWATER CALCULATIONS ACCORDING TO EQUATIONS BELOW:

$$e = ((d - c - b - a)/d)*100$$

$$f = ((g - c - b - a)/g)*100$$

WATER QUALITY MANAGEMENT ON WESTSIDE OF SAN JOAQUIN VALLEY-BRITZ PROJECT I. GROUNDWATER QUALITY MAPPING

J.E. Ayars, J. Penland, R.A. Schoneman, B. Meso, and J. Trent

OBJECTIVES: Monitor the electrical conductivity, boron and nitrate concentrations in the shallow groundwater below the demonstration fields over time to determine the influence of agronomic practices on water quality.

PROCEDURES: Shallow groundwater observation wells constructed of 38 mm PVC pipe were installed to a depth of 3.0 m throughout the research site as shown in Figure 1. Neutron access tubes were installed adjacent to the wells as shown in Figure 1. Water samples were collected approximately every two weeks and analyzed for electrical conductivity, boron, nitrate, selenium and most major anions and cations. Iso-concentration maps of chemical constituents in the shallow groundwater were prepared using the topographical plotting system found in the program "Surfer".

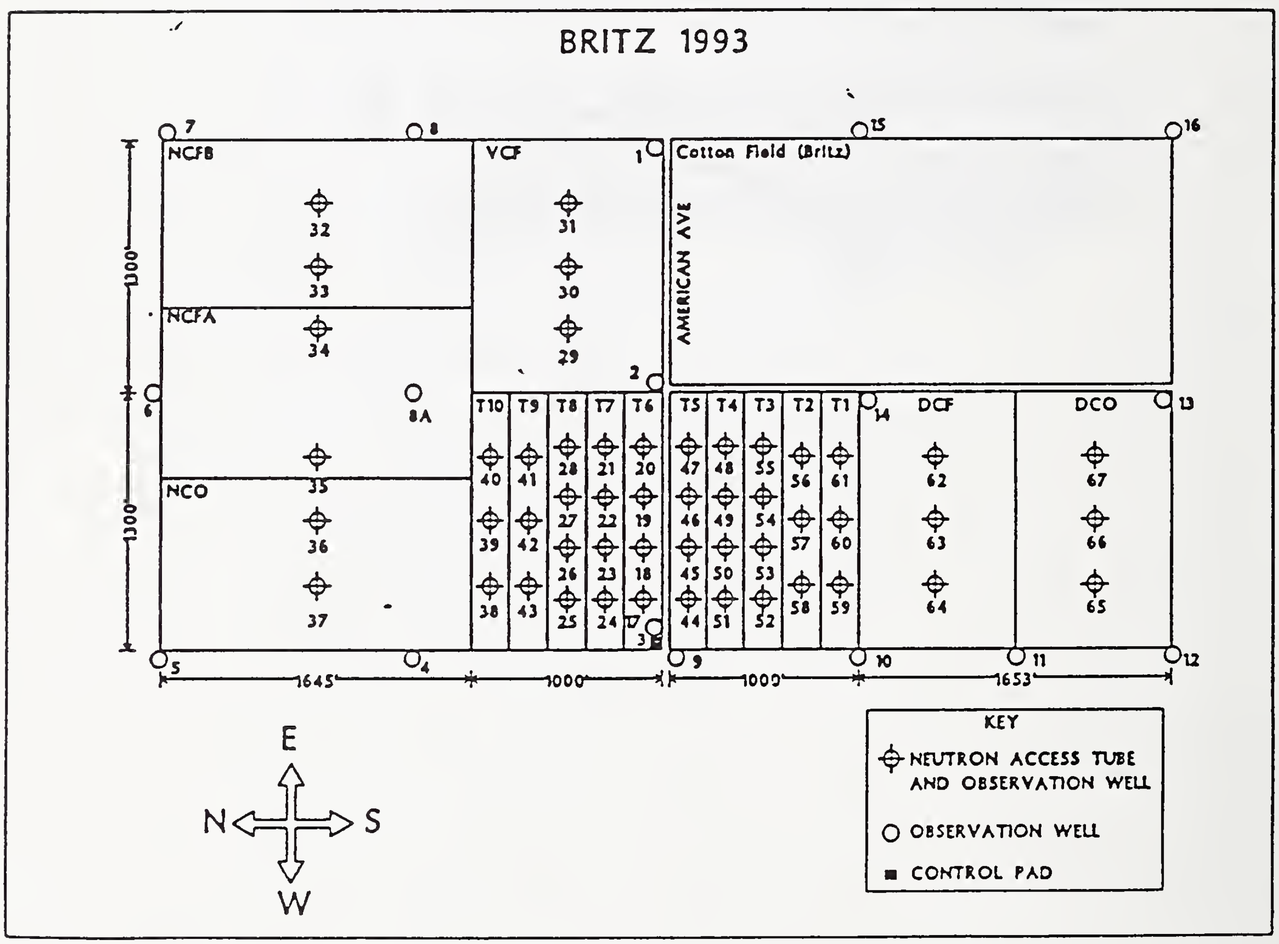

Figure 1. Plot layout of neutron access tube and observation wells used at Britz site in 1993.

RESULTS: Examples of the prepared maps are shown in Figures 2 and 3. Figure 2 shows the distribution of electrical conductivity in the shallow groundwater on June 17, 1993. The values range from 3 to 8 dS m^{-1}. The locations of the drip and furrow plots and the individual crops are also shown on the map. The data give a general idea of the distribution of salinity under the fields. As was noted in the 1992 Water Management Research Laboratory Progress Reports, if an extreme individual concentration is included in the analysis the distribution can become distorted. This presentation does high-light the variability which is found in field sites. The boron data taken at the same time as the electrical conductivity data are shown on Figure 3. The data range from 2 to 16 mg L^{-1}. The highest boron concentration value was found at the same location as was the highest EC value. In general the boron concentrations in the groundwater range between 2 and 4 mg L^{-1}.

FUTURE PLANS: This plotting strategy will be used to analyze water quality data in both the shallow groundwater and the soils. These data will be presented in reports to cooperators and in manuscripts.

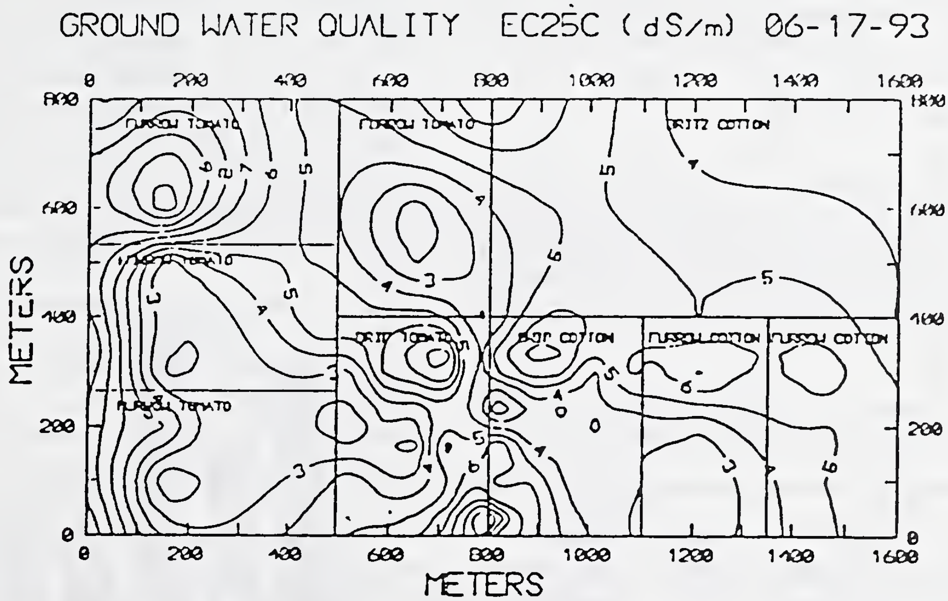

Figure 2. Representative plot of electrical conductivity of shallow groundwater under Britz site on June 6, 1993.

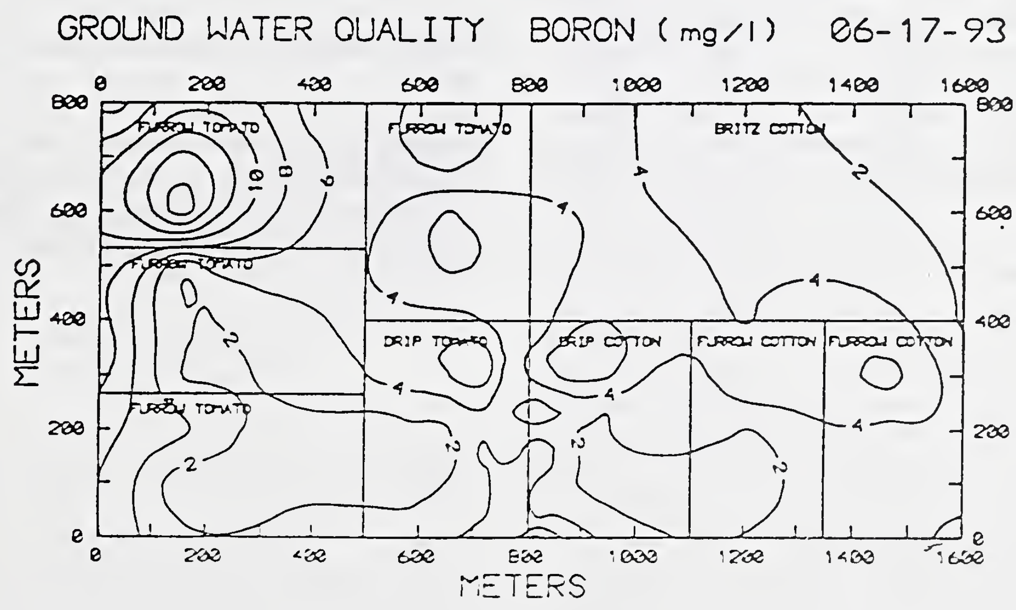

Figure 3. Representative plot of boron concentration in shallow groundwater under Britz site on June 6, 1993.

WATER QUALITY MANAGEMENT OF SAN JOAQUIN VALLEY -BRITZ PROJECT II. COTTON YIELD

J.E. Ayars, J. Penland, R.A. Schoneman, B. Meso, and J. Trent

OBJECTIVE: Determine the yield of cotton in each of the drip plots and compare the yields with the 1992 data.

PROCEDURES: Cotton (Acala, var. MAXXA) was planted April 14, 1993, at a seeding rate of 18 kg ha^{-1}. Germination was observed on April 27, 199. Defoliation was done October 26, 1993. Yields were determined by harvesting enough cotton to fill a module and then determining the harvested area. Plant populations were determined by counting numbers of plants in a 3 meter length of row.

RESULTS: in 1993 the plant population ranged from 63 to 80,000 plants per ha. while in 1992 the population ranged from 85 to 108,000 plants per ha. The yields and plant population data for 1992 and 1993 are given in Table 1.

Table 1. Summary of cotton yield and plant populations in plots 1-5 in 1992 and 1993.

Plot	1992 Lint (kg/ha)	1992 Plant Pop.#/ha (1000)	1993 Lint (kg/ha)	1993 Plant Pop.#/ha (1000)
1	827	88	2340	80
2	863	103	1925	73
3	893	85	2550	78
4	992	107	1797	63
5	972	108	1696	80

The yield in the individual plots was significantly lower in 1992 than in 1993. There was approximately the same amount of water applied each year and there was shallow groundwater available to the cotton each year. The plant populations were roughly the same between years. The plant populations were roughly the same between years. In general 1993 was considered a good year for cotton in the San Joaquin Valley and these data would support this. The yield in 1993 ranged from 3.5 to 5.5 bales per acre, which is very good. The yields in the drip plots are compared to the yield in the furrow irrigated plots DCF1, DCF2) in Figure 1. These data show that the drip yields were higher than the furrow irrigated plots.

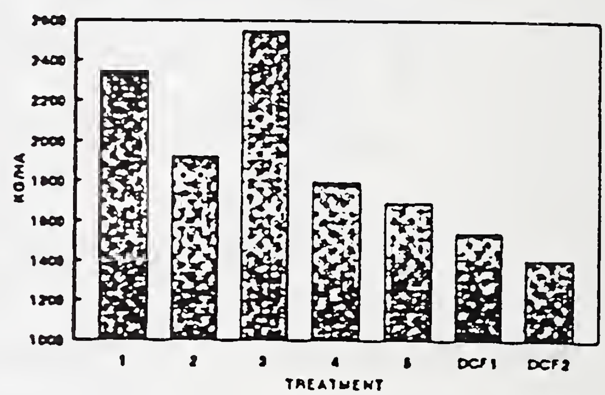

Figure 1. Britz Project machine harvest cotton yield in 1993.

FUTURE PLANS: These data will be used to prepare a manuscript on the management of irrigation systems in the presence of shallow groundwater.

WATER QUALITY MANAGEMENT ON WESTSIDE OF SAN JOAQUIN VALLEY-BRITZ PROJECT III. EVALUATION OF SDI SYSTEM LATERAL REPAIRS

B. Meso, R.A. Schoneman, F. Dale, J. Penland, and J.E. Ayars

OBJECTIVE: Determine the factors contributing to dripper tubing damage.

Table 1. Summary of Britz Project dripper tubing damage for 1993.

Drip tubing damage per treatment

Field	Trt#	Gophers	Cuts	Obstruction	Disconnect	Total
S1	1	10	2	6	2	20
	2	2	2	2	0	6
	3	3	3	0	3	9
	4	6	3	3	0	12
	5	10	3	3	1	17
S36	6	10	7	2	2	21
	7	4	10	2	0	16
	8	4	10	0	2	16
	9	0	1	1	0	2
	10	2	0	15	0	17
Total:		51	41	34	10	136

Damage caused per tubing type

	Trt#	Gophers	Cut	Obstruction	Disconnect	Total
Roberts	1,10	12	2	21	2	37
Ram	2,9	2	3	3	0	8
Chapin	3,8	7	13	0	5	25
Typhoon	4,6	16	10	5	2	33
T-system	5,7	14	13	5	1	33
Total		51	41	34	10	136

METHODS: When the SDI system was started in the spring, leaks appeared in furrows that caused surface runoff or large wet spots spanning more than one plant row. These were deemed serious enough for repair. Shovel work was required to expose the damaged section of tubing. Periodically this required digging up several meters of rodent tunnel before actual exposure of the leak. Scissors were used to cut out the damaged length of tubing and a new length of tubing was installed with couplings. The lateral was re-buried taking care to support it underneath with backfill before full burial. The cut out section was then assessed for cause. In particular, the edges of the perforation were studied for appearance. If the edges were frayed and/or the hole was shaped as a symmetrical curve (half of an ellipsoid) rodent or insect damage was recorded as the cause. If the perforation was shaped as a straight line with sharp edges, the cause was cutting by cultural practices. Obstruction by sedimentation or twisting and disconnections, as causes, were apparent when exposed.

RESULTS: Table 1 lists tubing damage of different types by treatment and dripper tubing brand. The table lists only the damage that was repaired by Water Management Laboratory personnel. Other damage was observed but not repaired due to constraints on resources. The data show that most damage was due to rodent chewing. Cuts from cultural practices influenced by improper seedbed to dripperline orientation ranked second. Next on the list were obstruction from sedimentation or twisting. Lastly, disconnections caused the least number of repaired leaks. The factors contributing to this are the presence of rodents and insects, tractor field work, and the lack of work coordination with the Cooperator. Gophers and mice settled into the SDI plots after escaping from the subsoiled furrow irrigated plots, causing chewing and tubing perforation damage. To control their presence, the chemical product "Vapam" was injected into the SDI laterals thirty days before planting. Following break-down of the chemical in the soil, a new migration into the SDI plots occurred. Tubing obstructions and punctures were found in the driplines, particularly in the "Roberts" tubing. Presumably, this damage was perpetrated by insects in the

sub-soil. Roberts driplines have a thin wall and are more susceptible to insect damage. Tractor fieldwork such as discing, bedding, and cultivation appear to have caused cutting and tubing stretch damage. In plot six and seven we reinstalled more than 55 meters (180 feet) of broken tubing. The cooperator failed to comply to the project work recommendation in establishing crop beds. This process requires that driplines be maintained in the middle of the rows, which permits good water distribution and its maximum use by the plants. Failing to respond to this recommendation, problems were observed such as tubing displacement and shallowness, and uneven plant development.

FUTURE PLANS: These data and similar data from previous years will be summarized and used in reports and a manuscript.

WATER QUALITY MANAGEMENT ON WESTSIDE OF SAN JOAQUIN VALLEY BRITZ PROJECT IV. TOMATO YIELD

J.E. Ayars, J. Penland, R.A. Schoneman, B. Meso, and J. Trent

OBJECTIVE: Determine the influence of irrigation management on tomato yields and quality in the presence of shallow groundwater.

PROCEDURES: Tomato (var Hunt 247) was planted at a seeding rate of 0.6 kg ha^{-1} on March 7, 1993. The machine harvest was begun August 4, 1993, with hand sampling taking place on July 21-22, 1993. Yields were determined during hand sampling by harvesting 6 m of row and separating the fruit into large and small red and green tomatoes and limited use tomatoes. There were 6 harvest replications in each plot. Samples were taken from each plot for determination of soluble solids. The machine harvest yields were determined using the measured area which was harvested to fill a set of tomato trailers, and the weight of the tomatoes in the trailers. The hand harvest yields were taken in areas of good plant growth and development while the machine yields also included areas with poor growth and development.

RESULTS: The yield data are summarized in Tables 1 and 2 and in Figures 1 and 2. The data in Table 1 are for the machine harvested fruit and include only the red fruit, both large and small. The soluble solids are also given for the machine harvest. Drip plots 6, 8, and 10 had higher machine harvest yields than the furrow irrigated plot AFA. In 1991 all of the drip irrigated plots had higher yields than did the furrow irrigated plots. This year the yield in all plots was reduced by nematode damage and poor stand development not associated with nematodes. The soluble solids were highest is the fruit from the furrow irrigated plot. The machine and hand harvest yields are summarized in Figure 1. Analysis of the hand harvest results give more insight into the influence of subsurface drip irrigation on tomato production and management. The yield components from the hand harvest are summarized in Table 2 for both the drip irrigated and furrow irrigated plots. The hand harvest areas in both the drip and furrow irrigated plots were selected to not include areas with problems. When all the components are included all of the drip plots had greater yields than did the furrow irrigated plots. If only the red components are considered all but one drip plot out-yielded the furrow plot. The drip plots had consistently more green tomatoes than did the furrow plot. This means that the harvest should have been delayed to permit ripening or that the management has to be changed to start ripening sooner in drip irrigated plots. Also, there were fewer limited use tomatoes in the drip plots than in the furrow irrigated plots. The highest yielding drip plot produced 23 t ha^{-1} more than did the furrow irrigated plot. The individual yield components are summarized in Figure 2.

Table 1. Machine harvest yields for Britz demonstration site. Plots 6–10 were subsurface drip irrigated and AFA was furrow irrigated.

Plot	Tomato Yield t ac^{-1}	t ha^{-1}	BRIX
6	49.9	111.9	4.7
7	32.7	73.3	4.7
8	38.1	85.4	4.8
9	31.6	70.8	4.9
10	41.6	93.3	5.3
AFA	38.3	85.9	5.4

Table 2. Hand harvest yield components for Britz project in 1993.

	Yield Components (t ha^{-1})				
Plot	Lg. Red	Sm. Red	Lg. Grn	Sm. Grn.	Ltd.
6	95.5	18.6	19.2	8.5	4
7	43.4	43.1	18.7	17.8	3.8
8	60.3	47.3	16.5	10.2	3.2
9	81.9	15.8	11.4	5.5	3.2
10	83.9	16.3	4.1	3.6	3
AFA	56.5	34.1	5	2.6	4.9

<u>FUTURE PLANS</u>: These data and yield data from previous years will be summarized and used in reports and in a manuscript.

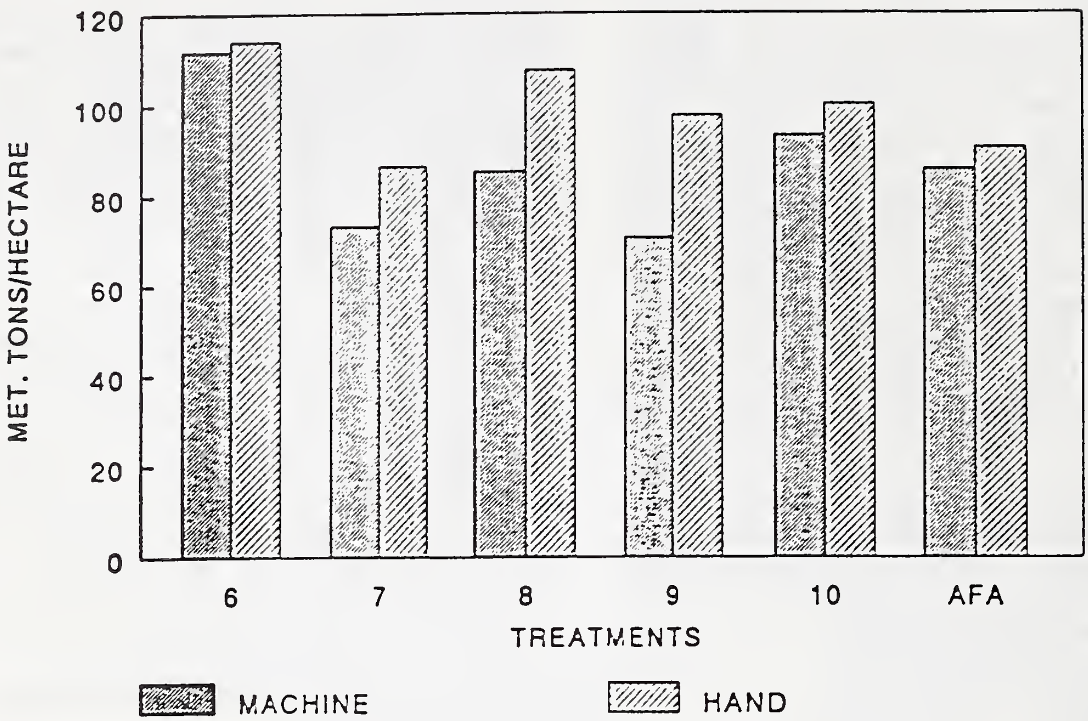

Figure 1. Britz Project tomato yields for 1993.

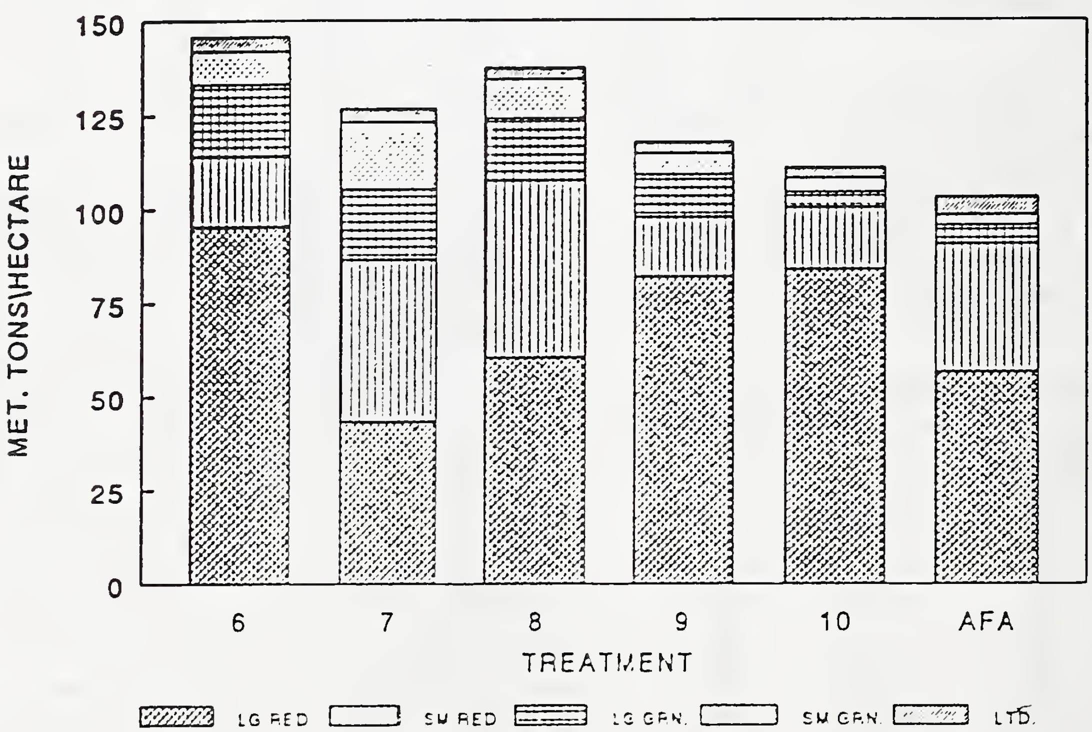

Figure 2. Britz Project tomato yield components in 1993.

WATER QUALITY MANAGEMENT ON WESTSIDE OF SAN JOAQUIN VALLEY BRITZ PROJECT V. GROUNDWATER RESPONSE TO IRRIGATION

J.E. Ayars, J. Penland, R.A. Schoneman, B. Meso, and J. Trent

OBJECTIVE: Measure the water table response to irrigation of tomatoes and cotton.

PROCEDURES: Depth to the water table was measured weekly during the summer at the well locations shown on Figure 1 in the progress report "*Water Quality Management of San Joaquin Valley-Britz Project I. Groundwater Quality Mapping*". The elevations were determined relative to a datum established at the drip system control pad. All of the observation wells in a plot were averaged to give a single depth to water.

RESULTS: The change in water table depth under the tomato plots is shown in Figure 1. Plots T6 to T10 are the drip plots and the remaining plots were furrow irrigated. The first seasonal furrow irrigation was on May 5, 1993, and the subsurface drip irrigation was begun on May 4, 1993. The furrow irrigation applied 50 to 100 mm each application while the drip system applied only 4 mm each application. The furrow irrigation occurred every 7 to 10 days while the drip was irrigated up to twice a day.

In Figure 1 the water table was at a depth of approximately 2 m below the soil surface under the tomatoes prior to irrigation. After irrigation began there was steady rise of the water table toward the soil surface. The minimum depth to water occurred on June 26, 1993. Irrigation was stopped not long after this and the depth to groundwater gradually increased. The rise in the water table was in response to the furrow irrigation and excessive deep percolation losses.

The water table response under the cotton is shown in Figure 2. The depth to water was between 1 and 1.5 m at the beginning of the season. There was a slight rise in the water table after irrigation was begun. This rise was followed by a steady decline for the reminder of the season. The ultimate depth to water was in excess of 2 m. The cotton received fewer furrow irrigations than did the tomatoes and the drip irrigation was consistently under-irrigated by design. The decline of the water table suggests that there was groundwater use by the crop in addition to any lateral flow which might have contributed to lowering the water table.

FUTURE PLANS: These data will be used in a manuscript.

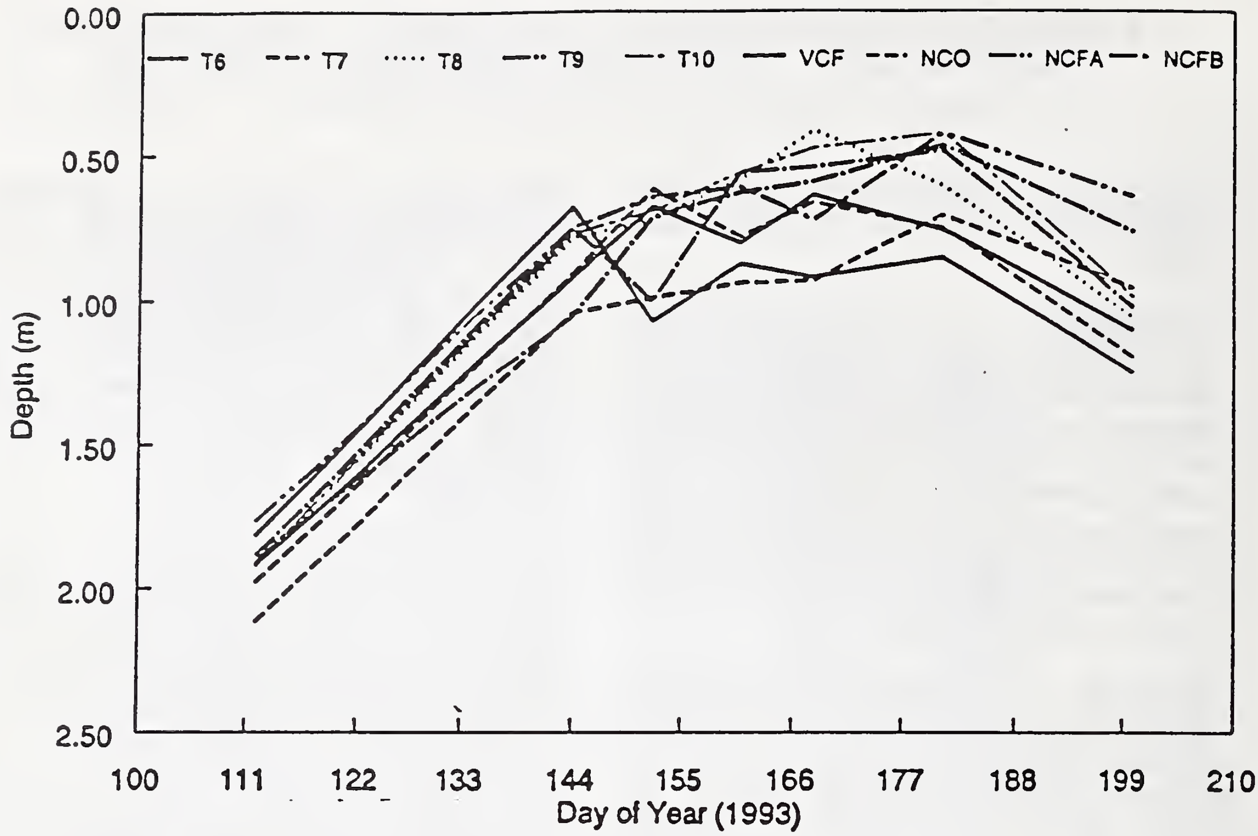

Figure 1. Britz tomato- plot water table response.

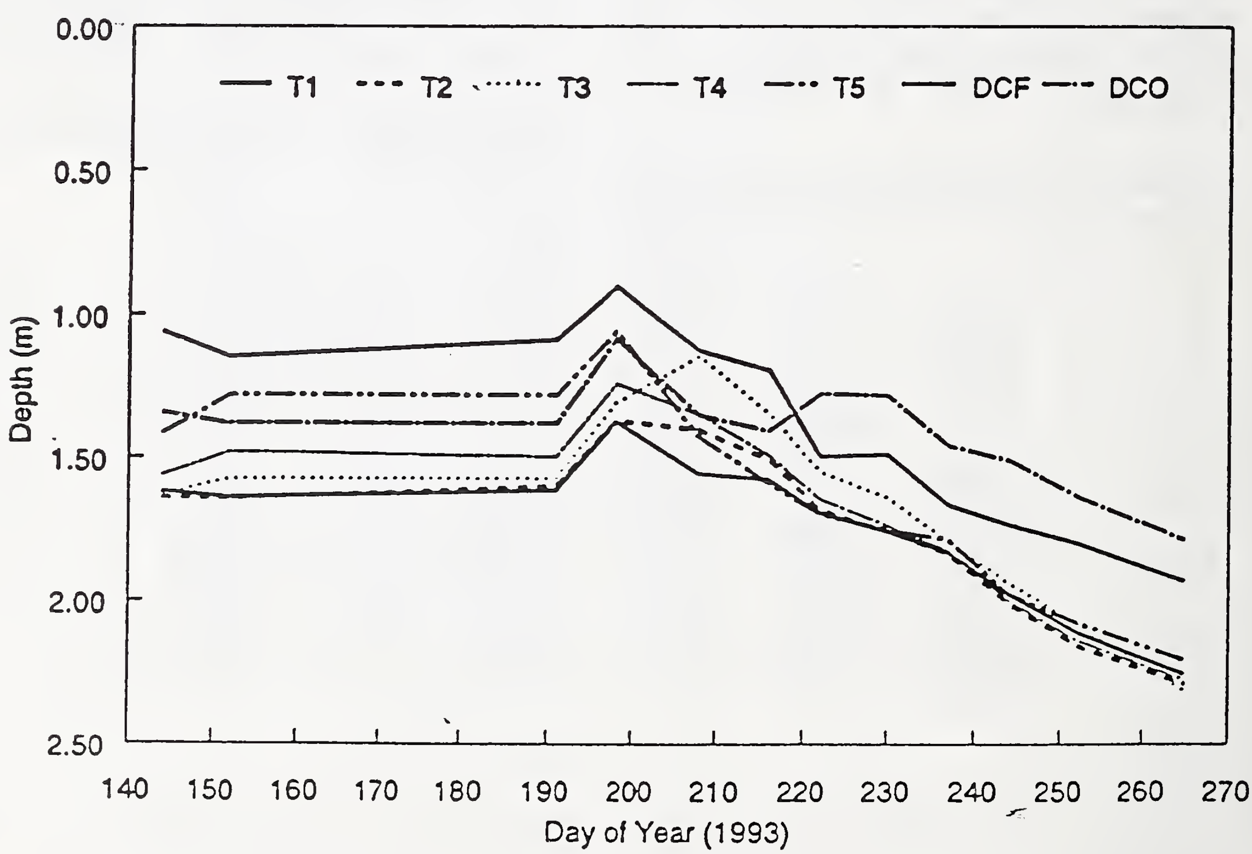

Figure 2. Britz cotton plot water table response.

WATER QUALITY MANAGEMENT ON WESTSIDE OF SAN JOAQUIN VALLEY-BRITZ PROJECT VI. DISTRIBUTION OF SALINITY ACROSS TOMATO BEDS

J.E. Ayars, J. Penland, R.A. Schoneman, B. Meso, and J. Trent

OBJECTIVE: Characterize the distribution of soil water and chloride in the soil water in relation to the tomato bed when the subsurface drip lateral is not centered under the bed.

PROCEDURES: Soil samples were taken in 15 cm increments to a depth of 60 cm in a transect perpendicular to the lateral. The sample sites extended across a full repeating pattern starting with a lateral centered under the bed and ending with a lateral centered under a bed. The soil was dried, ground, and saturated using standard methods. The saturation extract was analyzed for electrical conductivity, boron, chloride and nitrate.

RESULTS: The drip lateral position is shown relative to the bed for each year of the study in Figure 1. The soil was sampled in 1993 when a tomato crop was in the field. A poor plant stand and plant development prompted the soil sampling and analysis. The soil water content and chloride distribution at the 30-45 cm sampling depth are shown in Figure 2. This corresponds to the depth of placement of the drip laterals. The soil water content tends to be highest under each lateral and decreases away from the lateral. The chloride concentration pattern is the inverse of the soil water with the lowest concentration occurring under the lateral and the highest mid-way between the laterals. As can be seen in Figure 2, when the lateral is not centered the chloride is pushed to a region under the plant roots rather than away from the roots. This can result in poor plant growth and possibly death.

FUTURE PLANS: These results will be presented in a manuscript.

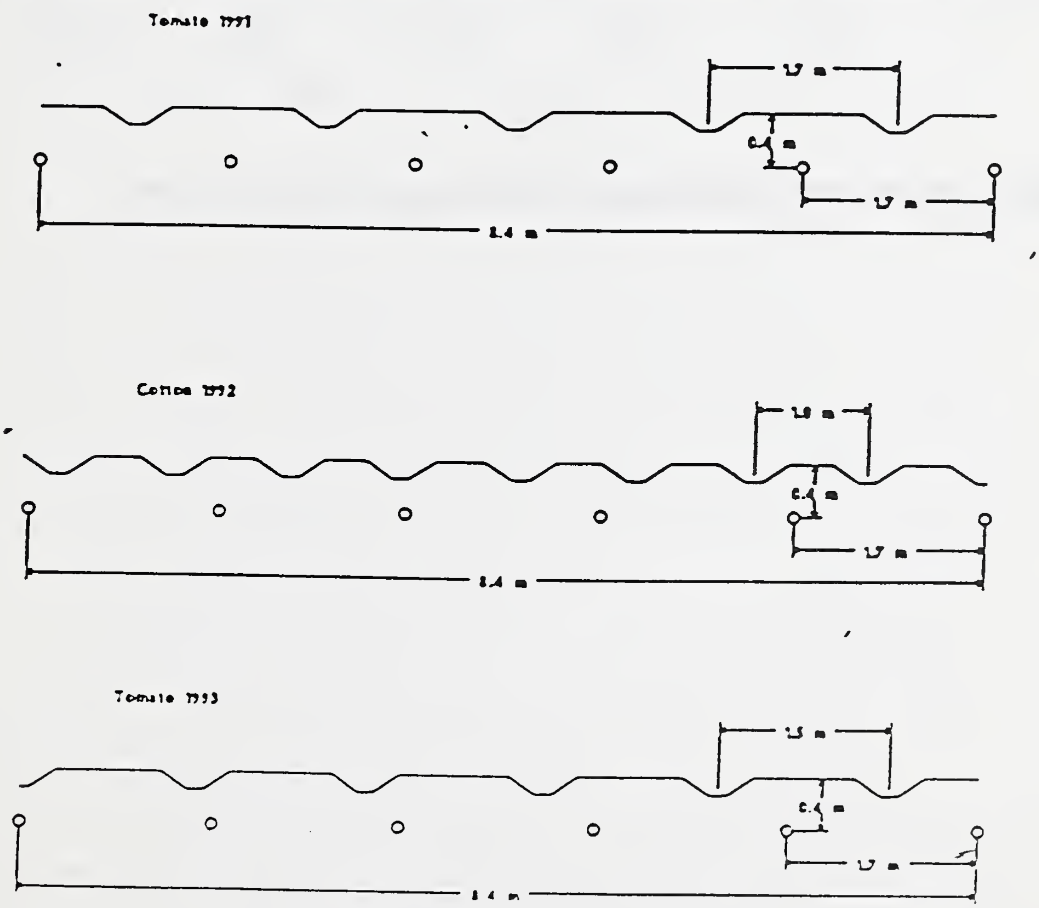

Figure 1. Britz Project seedbed to dripper tubing orientation in section 36.

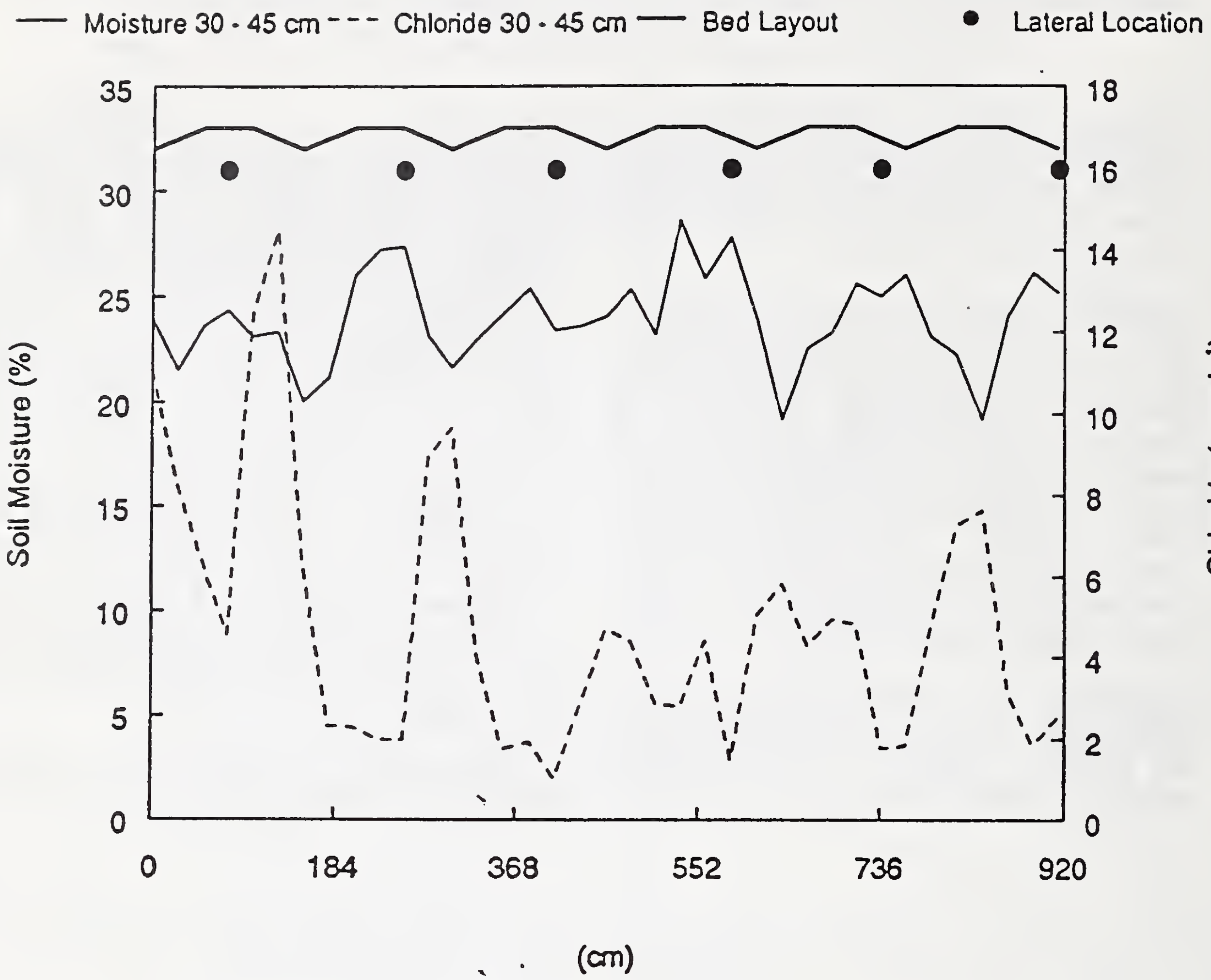

Figure 2. Britz Project soil water and chloride distribution across 6 tomato beds in 1993.

COMBINING MONOLITHIC AND REPACKED SOIL TANKS FOR HIGH WATER TABLE LYSIMETERS

A.D. Schneider, J.E. Ayars, C.J. Phene

OBJECTIVE: Develop methods for using combination monolith and backfilled tanks for lysimeter research in shallow groundwater areas with well developed salinity profiles.

PROCEDURES: Figure 1 shows the schematic of the monolith tank and the frames designed to control the entry of the tank into the soil. Dead weight was used to push the tank into the ground while the soil was excavated to a depth of 30 cm below the cutting edge of the tank. Figure 2 shows the end view of the tank and the frames used to control the downward movement. A chain hoist at each corner of the tank was used to control the descent of the tank. After the tank was completely inserted, the monolith was undercut using the equipment shown in Figure 3. A 91 Mg crane was used to lift the soil monolith out of the ground and place it on a truck which hauled it to Parlier where it was readied for installation. Soil was excavated below each monolith for use in back-filling the bottom section of the tank. The combined depth of both tanks was 3 m. The bottom tank was hand filled to a density of approximately 1.3 Mg m^{-3}.

RESULTS: After the bottom tank was filled the top section was lifted over the bottom section and welded together. Each of the systems worked exceptionally well and 2 monoliths were extracted in approximately 4 working days with the aid of 5 men and a backhoe. This approach was possible through the use of heavy equipment.

FUTURE PLANS: A manuscript is in preparation and a video has been made of the process. The video will be part of a package which describes the construction of the lysimeter which will house these monoliths.

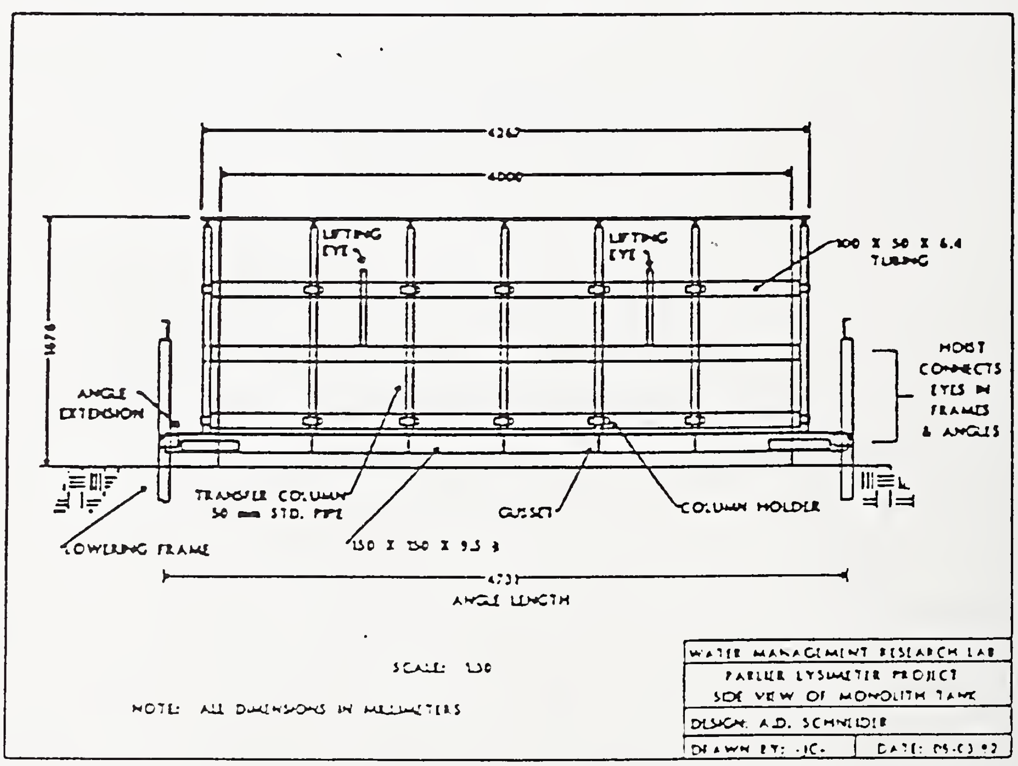

Figure 1. Monolith tank and lowering frame.

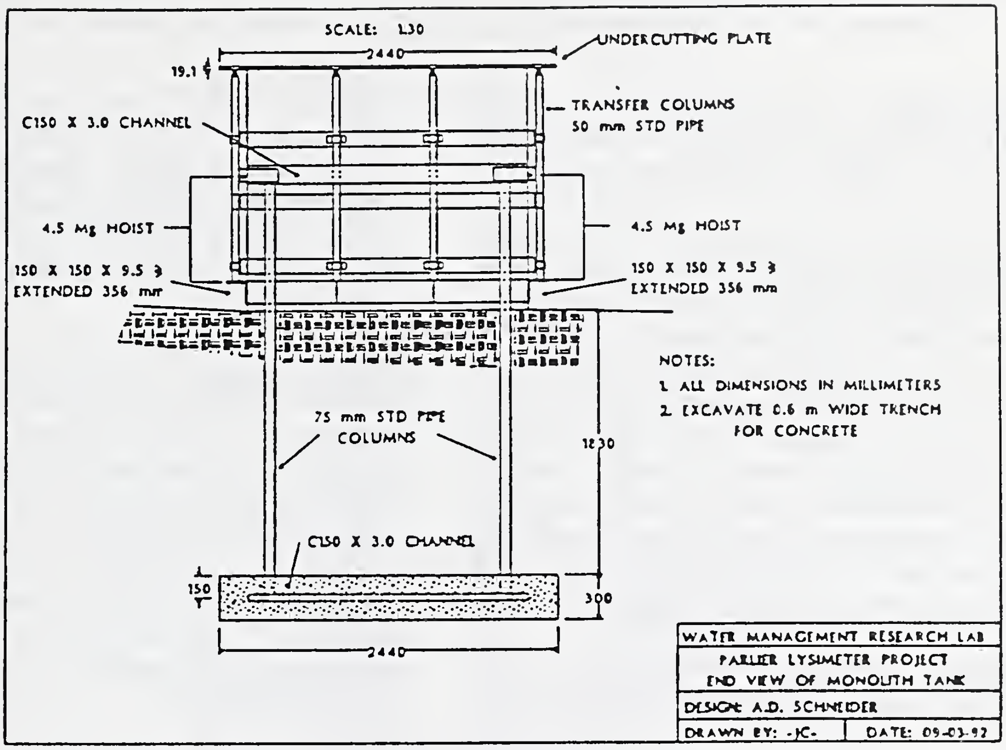

Figure 2. Monolith tank lowering frame detail.

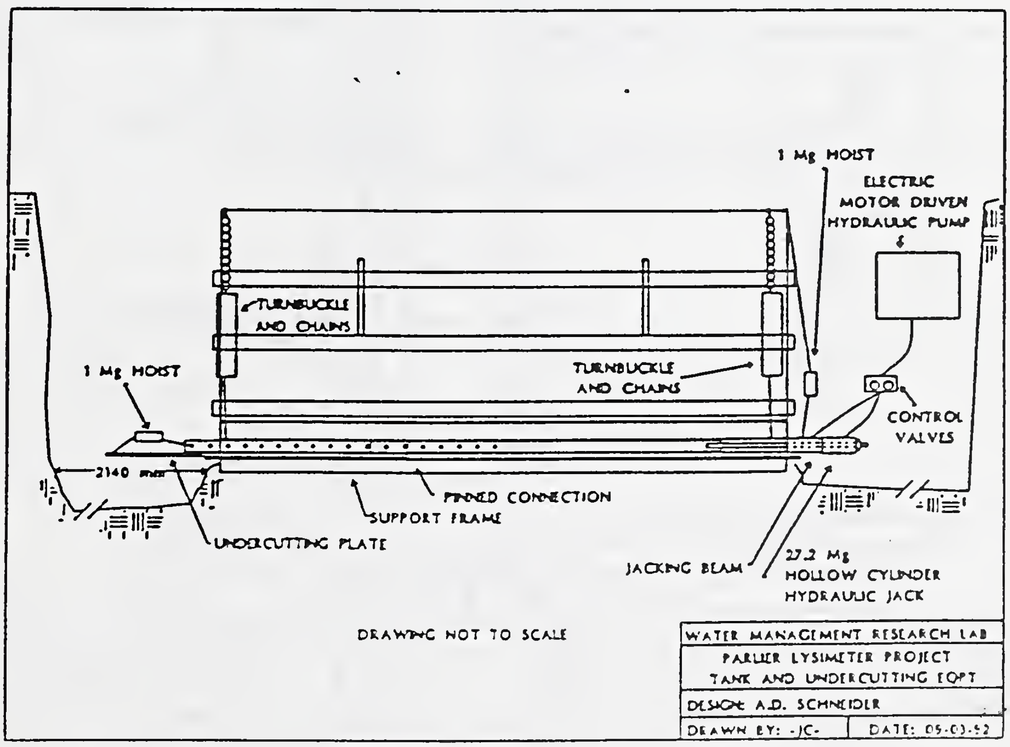

Figure 3. Undercutting equipment.

SHALLOW GROUNDWATER MANAGEMENT IN THE BROADVIEW WATER DISTRICT

J.E. Ayars, R.A. Schoneman, W. Unger, D. Cone, H. White, and F. Dale

OBJECTIVE: Develop and test a control system for subsurface drains installed in areas with shallow saline groundwater.

PROCEDURES: A cooperative agreement was established with Cilker Orchards in the Broadview Water District to permit the installation of control structures on a drainage system installed on 160 acres of land. A control structure similar to that shown in Figure 1 was constructed for installation on each lateral. Control structures similar to the schematic shown in Figure 2 were constructed for installation along the main. The proposed location of each structure is shown in Figure 3.

RESULTS: The memorandum of understanding was completed with Cilker Orchards and the materials were purchased to begin construction of the control structures. Broadview Water District agreed to purchase the materials needed for the controls and assist in the construction and installation of the equipment.

FUTURE PLANS: The controls will be installed in the spring and a series of observation wells will be installed to monitor the groundwater response. The irrigation on this field will be monitored to determine the effect of groundwater management on the irrigation efficiency. Groundwater quality will also be monitored to assist in the management process. This project will run for at least three years.

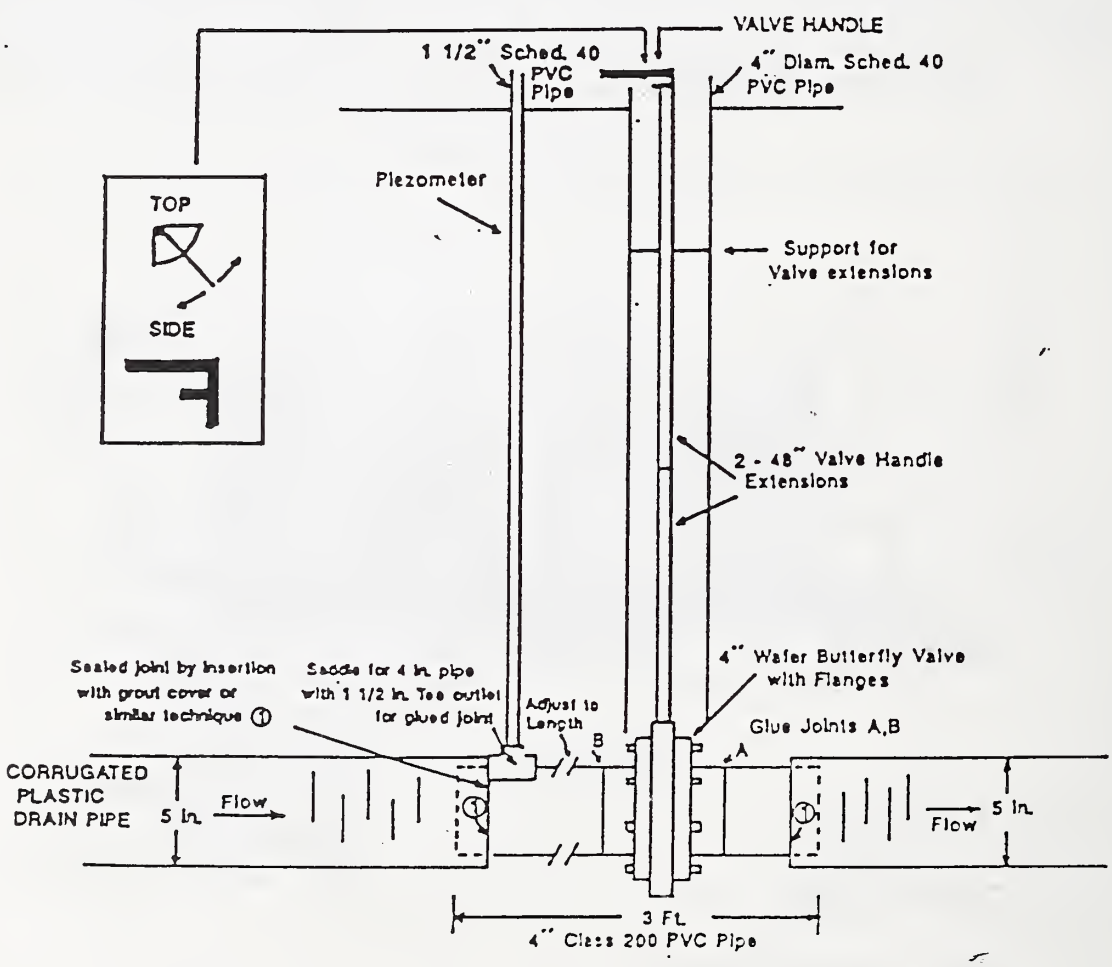

Figure 1. Lateral control structure used in shallow groundwater management project.

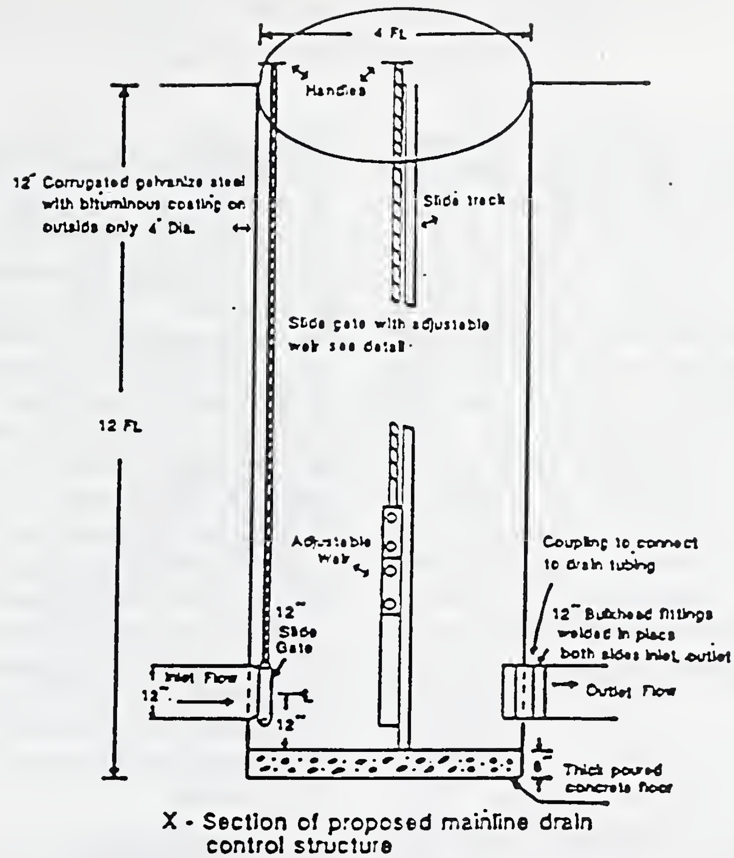

Figure 2. Schematic of mainline control structure used in shallow groundwater management project.

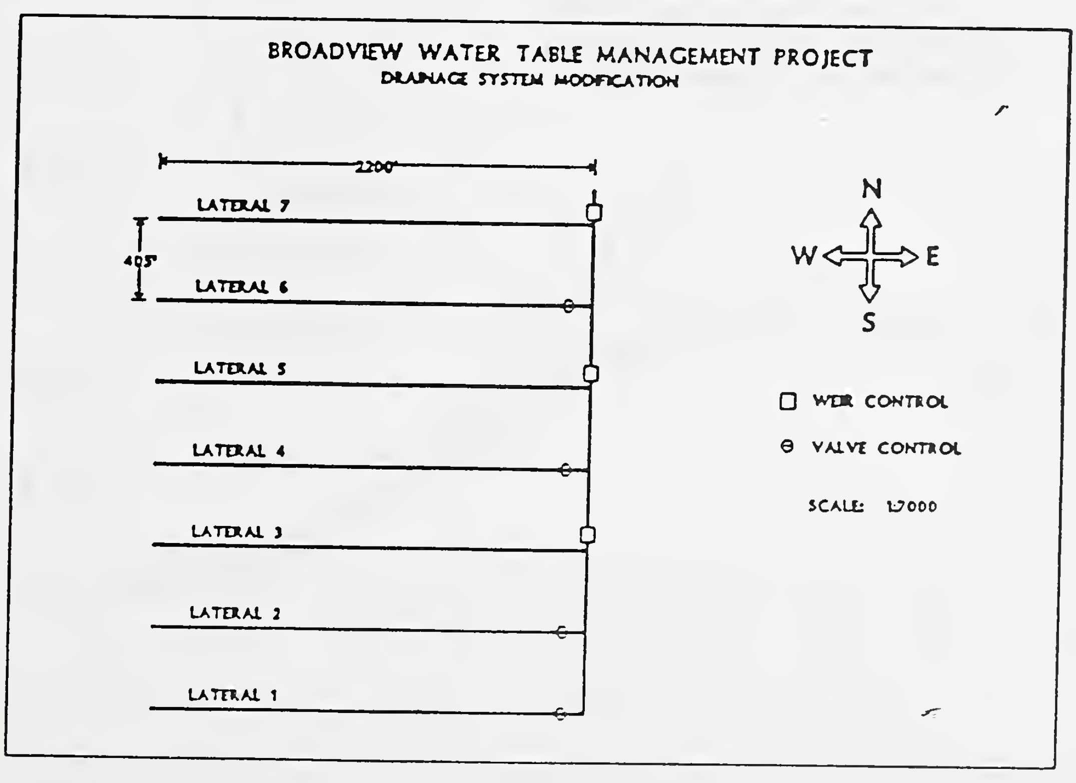

Figure 3. Control structure location in shallow groundwater management project.

CROP COEFFICIENTS FOR IRRIGATION SCHEDULING OF COTTON IN THE PRESENCE OF SHALLOW GROUNDWATER

J.E. Ayars and R.B. Hutmacher

OBJECTIVES: Develop a crop coefficient for use in irrigation scheduling of cotton in the presence of shallow saline groundwater.

PROCEDURES: Cotton water use from shallow groundwater was characterized as a percentage of the daily evapotranspiration using column lysimeters 1.8 and 2.6 m in length. The groundwater contribution was determined as a function of depth to water table and shallow groundwater quality. Groundwater quality was determined as a multiple of the Maas-Hoffman threshold for yield reduction. Electrical conductivities of 0.3, 7.7, 15.4, 23.1, and 30.8 dS m^{-1} were used in the study. The Maas-Hoffman threshold for cotton is 7.7 dS m^{-1}. The percentage crop water use was used to modify the cotton basal crop coefficient such that the use of the resulting coefficient would account for the groundwater contribution to crop evapotranspiration as a function of plant development. The percent contribution was matched to the basal crop coefficient using accumulated growing degree days to base of 13°C.

RESULTS: Figure 1 shows the percentage of groundwater contribution to cotton water use as a function of groundwater quality and depth to the water table as determined in the column lysimeters. Cotton used approximately the same amount of water from the water table for all groundwater qualities up to 15.4 dS m^{-1}, which is twice the Maas-Hoffman threshold value. With the deeper water table the contribution was delayed compared to the contribution from the shallower water table. Figure 2 shows the modified crop coefficients for 5 groundwater qualities and 2 depths along with the base crop coefficient for cotton. As the groundwater becomes more saline or the depth to groundwater increases, the groundwater contribution decreases, and the curve approaches the base curve.

FUTURE PLANS: A manuscript will be prepared using this data.

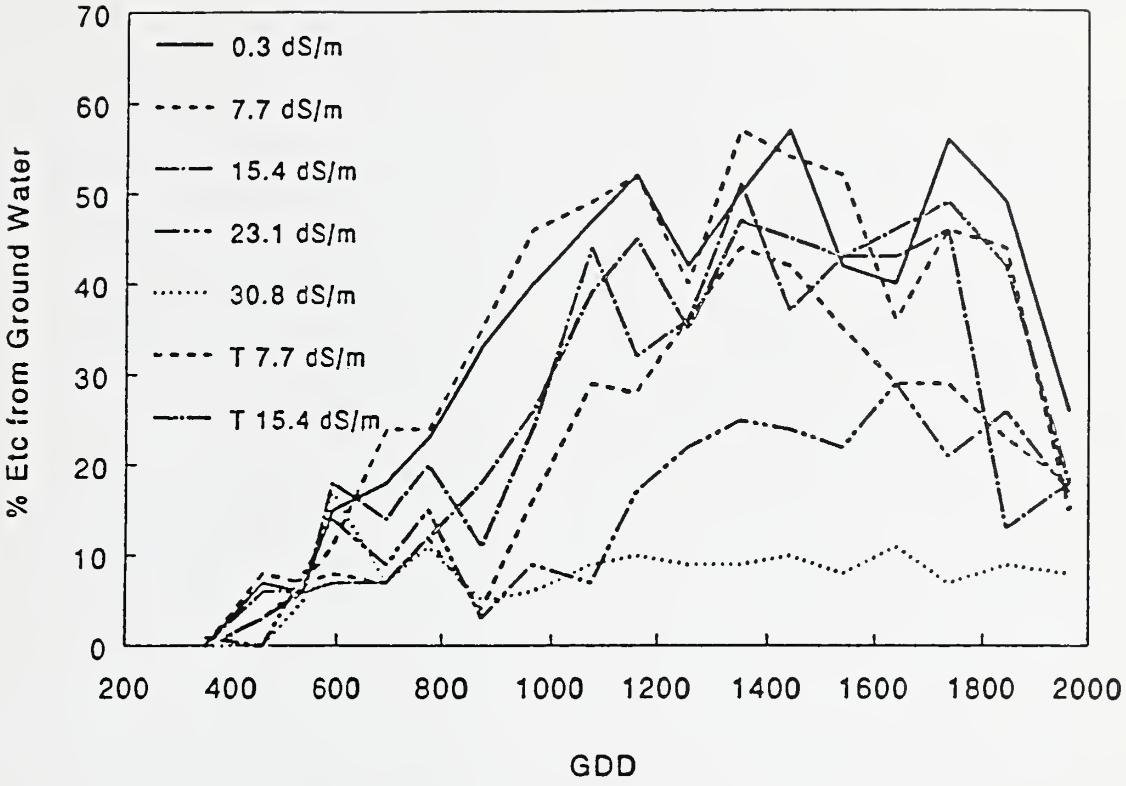

Figure 1. Percentage groundwater contribution to crop water use as a function for 2 depths to water table and 4 groundwater qualities growing degrees.

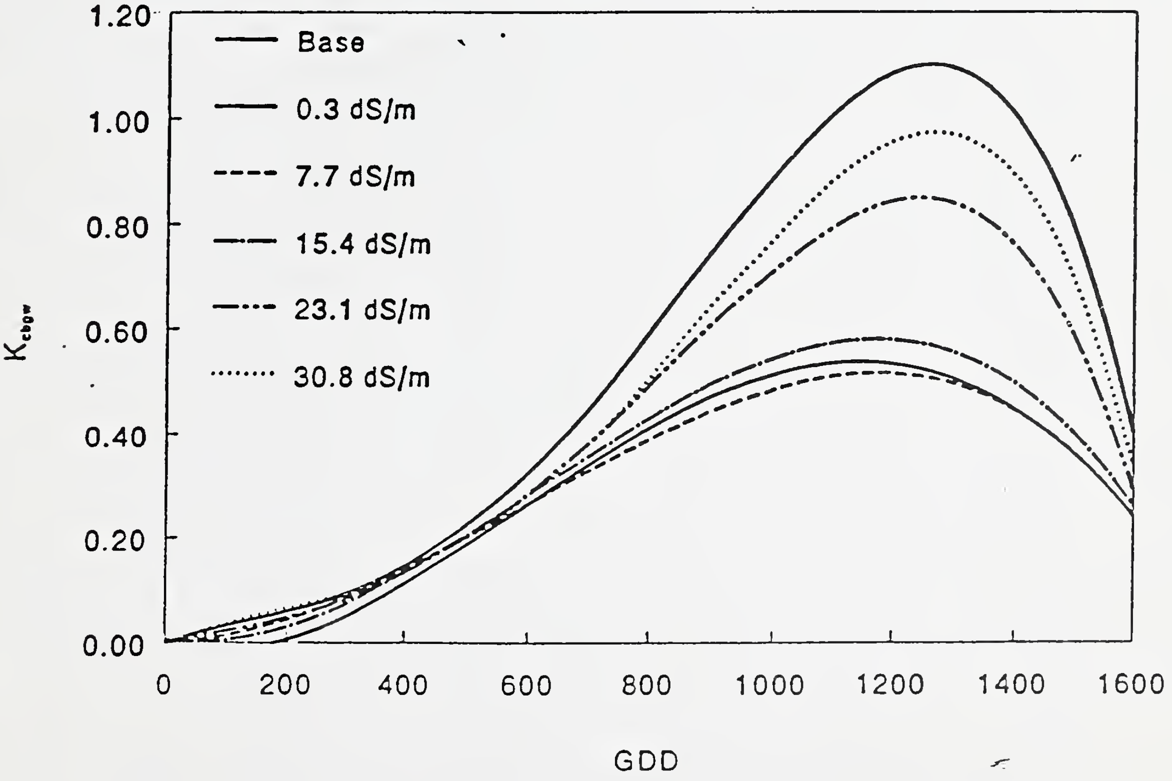

Figure 2. Crop coefficients modified to include groundwater use as a function of Growing Degree Days, 4 and 5 groundwater qualities.

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LYSIMETER MEASUREMENTS OF EVAPOTRANSPIRATION IN MATURING GRAPES

C.J. Phene, R.M. Mead, L. Williams, D. Clark, and P. Biscay

OBJECTIVES: To use a computerized weighing lysimeter system for determination of evapotranspiration and crop coefficient (K_c) of drip irrigated grapes; to control in a real time feedback mode surface and subsurface drip systems at several evapotranspiration rates in the research site surrounding the lysimeter; to produce a set of crop coefficient functions for years two through six for use with CIMIS to schedule irrigation of grapes in the San Joaquin Valley.

PROCEDURES: The lysimeter, including the water in the tanks, was weighed hourly to determine the evapotranspiration (ET_c) of the two grapevines; the mass change was compared to a threshold mass of 96 kg (8 kg 1 mm ET_c) and after 96 kg of mass loss the lysimeter was irrigated until the threshold mass was met. At midnight each day, the water tanks were refilled to a pre-set level; the volume of water was measured with an electronic flowmeter and the lysimeter mass was used as the baseline mass for the next day. Daily crop coefficients (K_c) were calculated by taking the ratio of ET_c/ET_o where ET_o is reference evapotranspiration. Reference crop ET (ET_o) was calculated from data collected at a CIMIS weather station located at the Kearney Ag Center, approximately 325 m from the Thompson Seedless vineyard used in the study. Soil water content was measured with a Troxler Model 3332 Depth Moisture Gauge (neutron probe). Daily sensor outputs from the lysimeter were transmitted via telecommunication to the WMRL microcomputer and basic data were stored on a hard disk and backed up on high density floppy disks.

RESULTS: Table 1 shows monthly summaries of rainfall, lysimeter ET_c, the reference evapotranspiration (ET_o), the lysimeter K_c, the actual vine K_c, and the number of lysimeter irrigations. As discussed in previous reports, the K_c tracks evapotranspiration and hence its accuracy in predicting ET_c is limited to ± 10%, especially on a daily basis. Each vine used approximately 6924 L of water. Reference ET_o was 1237 mm. There were 839 irrigations, totaling 1678 mm of applied water and 248 mm of rainfall. No drainage was collected from the lysimeter. The two vines in the lysimeter grew to a size approximately equal to the size of the vines in the surrounding vineyard.

FUTURE PLANTS: This experiment will be continued until the grape vines reach a fully mature stage.

Table 1. Monthly totals of rainfall, grapevine ET_c (lysimeter), reference ET (Et_o, CIMIS), lysimeter and grapevine K_c's, and number of irrigations.

Month	Rain (mm)	ET_c Lysimeter (mm)	CIMIS(ET_o) (mm)	Lysimeter K_c	Actual K_c* (7.52 m^2/vine)	# of Lysimeter Irrigations
Jan	NA	15	27	0.56	0.30	0
Feb	98	36	42	0.84	0.45	92
March	47	46	79	0.59	0.31	0
April	7	79	117	0.68	0.36	0
May	4	203	116	1.75	0.93	95
June	7	311	181	1.72	0.91	154
July	0	377	206	1.83	0.97	186
Aug	0	333	180	1.85	0.98	166
Sept	1	235	130	1.80	0.75	119
Oct	4	57	87	0.66	0.35	27
Nov	50	17	46	0.37	0.20	0
Dec	30	21	25	0.84	0.45	0
Total	248	1731	1237			839

*Based on vine to vine spacing in field.

LYSIMETER MEASUREMENTS OF EVAPOTRANSPIRATION IN MATURING PEACH TREES

C.J. Phene, R.M. Mead, S. Johnson, D. Grimes, D. Clark, and P. Wiley

OBJECTIVES: To use a computerized weighing lysimeter system for determination of evapotranspiration of maturing peach trees and to control micro-irrigation systems in a real time feedback mode at several evapotranspiration rates in the research site surrounding the lysimeter. To produce a set of crop coefficient functions for years two through six for use with CIMIS to schedule irrigation of peaches in the San Joaquin Valley.

PROCEDURES: A lysimeter with dimensions of 2 m wide by 4 m long by 1.5 deep, contained two peach trees planted 2 m apart and centrally spaced. The lysimeter (including the water in its irrigation tanks) was weighed hourly to determine the evapotranspiration (ET_c) of the two trees; the mass loss of the lysimeter was compared to a threshold mass of 96 kg (4 kg = 1 mm ET_c per tree), and after 12 mm (96 kg) of ET was measured, the lysimeter was irrigated until the threshold mass was met. At midnight the water tanks were refilled to a pre-set level; the flow of water was measured electronically with a flowmeter and the new lysimeter mass was used as the baseline mass for the next day. Daily outputs from the lysimeters were transmitted automatically via telecommunication to the WMRL microcomputer and basic data were stored on a hard disk and backed up on high density floppy disks.

RESULTS: Table 1 shows monthly summaries of rainfall, lysimeter ET_c grass reference ET_c (CIMIS), the lysimeter and actual tree crop coefficients (K_c's), and the number of lysimeter irrigations. Tree crop coefficients were established by dividing ETc by ETo on a summed monthly basis. As discussed in previous reports the K_c tracks evapotranspiration and hence its accuracy in predicting ET_c is limited to ± 10%, especially on a daily basis. Each tree used approximately 11,100 L of water. Reference ET_c was 1231 mm. There were 187 irrigations, totaling 2244 mm of applied water and 248 mm of rainfall. No drainage was collected from the lysimeter. The two trees in the lysimeter grew to a size approximately equal to the size of the trees in the surrounding orchard.

FUTURE PLANTS: This experiment will be continued until the peach trees reach a fully mature stage.

Table 1. Monthly totals of rainfall, peach tree ET_c (lysimeter), reference ET (Et_o, CIMIS) lysimeter and peach tree K_c's, and number of irrigations.

Month	Rain (mm)	ET_c Lysimeter (mm)	CIMIS(ET_o) (mm)	Lysimeter K_c	Actual K_c (8.91 m^2 /tree)	# of Lysimeter Irrigations
Jan	NA	17	27	0.63	0.28	0
Feb	98	41	42	0.98	0.44	0
March	47	53	78	0.68	0.31	0
April	7	155	114	1.36	0.61	0
May	4	336	115	2.92	.31	23
June	7	429	181	2.37	.07	36
July	0	614	206	2.98	.34	47
Aug	0	541	180	3.00	.35	44
Sept	1	331	130	2.55	.15	27
Oct	4	213	87	2.45	.10	10
Nov	50	28	46	0.61	0	0
Dec	30	17	25	0.68	0	0
Total	248	2775	1231			187

CAPACITANCE PROBE SOIL MOISTURE MEASUREMENTS (THE SENTEK-ENVIROSCAN SYSTEM)

R.M. Mead, J.E. Ayars, and J. Liu

OBJECTIVES: To evaluate a capacitance technique (Sentek-EnviroSCAN) for continuous soil moisture monitoring. The eventual installation of this system into new lysimeters at the Parlier facility will help understand soil water movement in a SDI profile in conjunction with and without water table conditions.

PROCEDURES: In November 1993, a Sentek-EnviroSCAN system was installed in a 1 M^3 wooden box filled with a sandy loam soil packed to a bulk density of 1.5 g/cm^3. Using accommodating installation tools, a specialized Sentek 49 mm PVC assess tube was vertically installed into the boxed soil. Eight Sentek-EnviroSCAN sensors were constructed onto a array which was inserted into the PVC access tube to monitor soil depths 10 to 80 cm having 10 cm spacing between individual sensors. A Sentek data logger with accompanying solar panel was connected to the sensor array. A rain gauge was installed within 2 m from the soil box to monitor precipitation experienced by the boxed soil. This preliminary arrangement was set up to test both hardware and software of the Sentek EnviroSCAN system.

RESULTS: Successful downloading from the Sentek EnvironSCAN system was obtained whereby graphics were displayed from any or all sensors through time. December rainfall was detected and observed with corresponding peaks followed by dramatic drainage troughs (Figure 1). Profile totals could be obtained by summing all individual sensor readings (mm/10 cm) together. Individual volumetric water content from each sensor would also be observed by toggling on the sensor of choice.

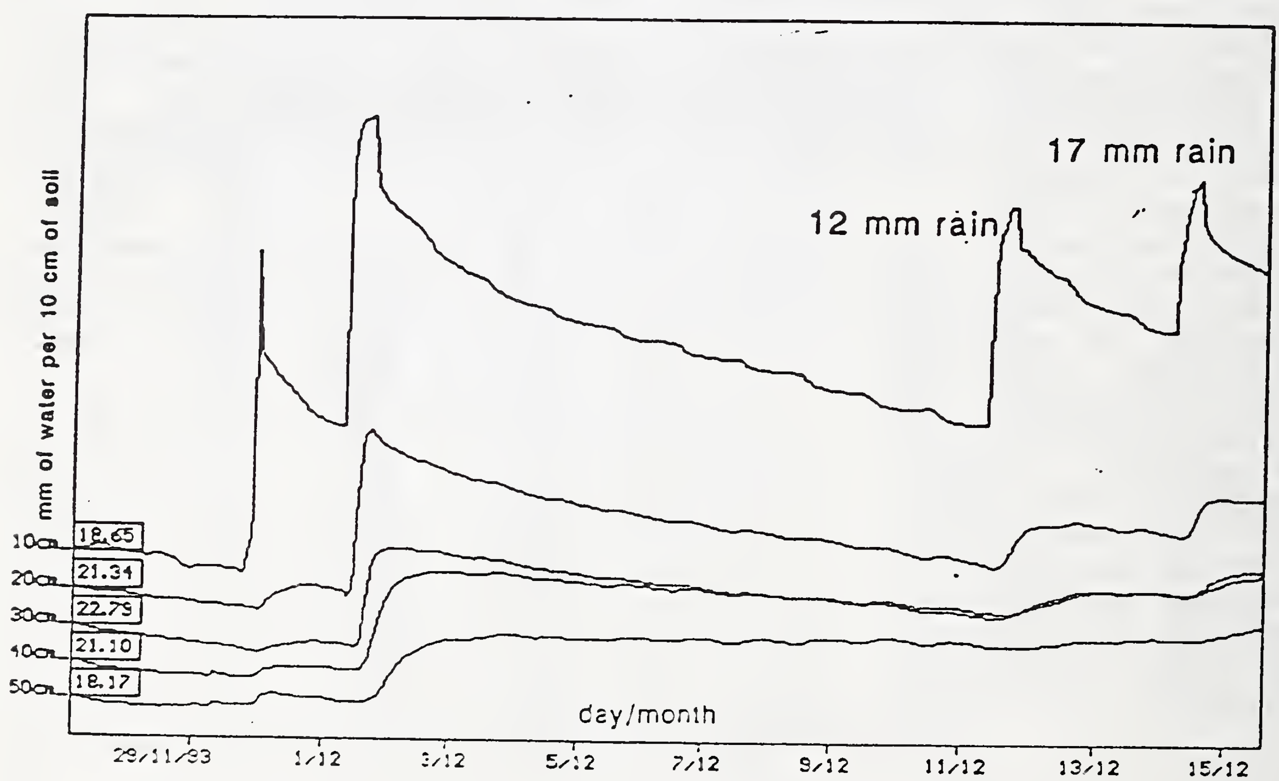


Fig 1. Sentek EnviroSCAN data as reported from a boxed sandy loam soil in Dec. 1993

FUTURE PLANS: Intensive calibration procedures will take place in specially designed bulk density chambers. A sand, sandy loam and clay soil will be tested inside the bulk density chambers. Two more wooden boxes will be constructed to match the initial wooden box's dimensions. Imposed surface drip irrigations onto the three boxed soil types will be monitored with the installed Sentek system. The Sentek EnviroSCAN system will be installed into a new series of lysimeter at the Parlier field station. Parlier lysimeters are situated side by side, and will represent a subsurface drip irrigation system responding to: (1) an imposed water table, and (2) non water table situation. The individual lysimeters have the dimensions of 2 m wide by 4 m long by 3 m deep. Sentek sensor arrays will be installed vertically and horizontally into the lysimeters. Plans are also being proposed for installation in a subsurface drip irrigated field and to monitor water movement vertically and horizontally from the buried emitter.

MATRIC POTENTIAL MONITORING OF SUBSURFACE DRIP IRRIGATED SOIL PROFILES

R.M. Mead, C.J. Phene, D. Clark, and R. Yue

OBJECTIONS: To observe soil matric potential throughout the profile of a subsurface drip irrigated field, specifically in three differentially buried dripline treatments.

PROCEDURES: Three major SDI placement depths exist at the University of California West Side Research and Extension Center's north lysimeter field (Field 27). Drip lines are installed at depths of 30, 45 and 60 cm below grade in the center of 1.6 m wide beds. In one block of this field in the spring of 1993 matric potential sensors were placed in each of the SDI treatments. Seven sensors were vertically installed approx-imately 45 cm away from the nearest emitter vertical plane and 5 cm north of the drip line vertical plane. The sensor depths were 15, 22.5, 30, 45, 60, 75, 90 cm below the soil surface. All sensors were collectively relayed to a central CR7 data logger. Input data was recorded hourly for each sensor and SDI treatment. Cotton (Maxxa variety) was grown in the field during the 1993 season.

RESULTS: Matric potential readings consistently displayed reasonable soil moisture profiles based on soil water transport principles. There were at times, errors or anomalies with particular sensors, but overall the sensors performed well. Earlier in the year (mid July), sensors showed less negative (wetter) readings in closer proximity to respective drip line depths (Figure 1). The 30 cm SDI treatment had the wettest average profile (-0.57 bars) in mid July, while the 60 cm SDI treatment had the driest (-1.5 bars). Toward the end of the year (mid October), each SDI treatment had the most water depletion around its respective drip line placement (Figure 1). The 30 cm SDI treatment had the most water extraction throughout the profile, having a drop of 1.45 bars on average. The only sensor areas that did not change through time (negatively or positively) was the top sensor (15 cm) in both the 45 and 60 cm SDI treatments.

FUTURE PLANS: Soil matric potential will be continuously monitored throughout the year in 1994. An oat crop is to be planted in the field until harvest, then fallowed until the fall in which a shallow rooted winter vegetable (broccolli) will be planted. Sensors will be invaluable in visually attaining soil moisture response to cropping under the three SDI treatments.

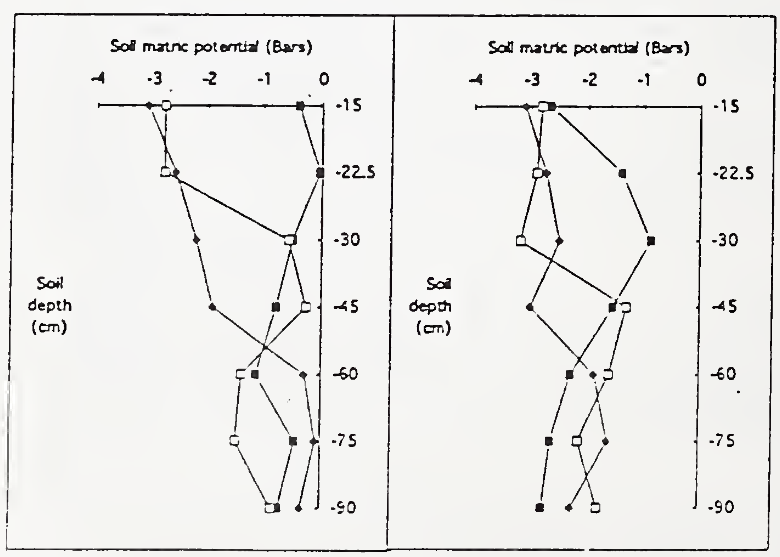


Figure 1

Soil matric potential with depth at mid-July and Mid-October, 1993.

■ = 30 cm

□ = 45 cm

◆ = 60 cm

CAPACITANCE PROBE USE IN SOIL MOISTURE MEASUREMENTS

I.C. Paltineanu, R.M. Mead, J. Liu, and J.E. Ayars

OBJECTIVE: To evaluate and compare the response of a capacitance technique versus traditional gravimetric and neutron probe techniques for measuring soil moisture.

PROCEDURES: Field experiments were conducted on a Panoche clay loam soil at the University of California West Side Field Station in plots planted with cotton (*Gossypium hirsutum*, var. Maxxa). Using a surface drip irrigation line having 4L Hr^{-1} emitters spaced 1 m apart, the plots were labeled: Wet, semi-wet, and dry to represent the amount of water applied. The wet treatment received 1153 mm which reflected crop water needs based on local climatological data. The semi-wet treatment received a total of 355 mm during the stages of seed germination and post fruit-set. The dry treatment received 114 mm for germination only. Each plot consisted of 3 beds with each bed having two cotton rows 70 cm apart and 1.7 m between furrows.

In the middle bed of each treated plot, one 50 mm schedule 40 PVC pipe, 2.5 m in length was installed to serve as an access tube for both neutron and capacitance probe readings. A Troxler* access tube guide plate was not available at the time of access tube installation, therefore all field 50 mm access tubes were installed using a Giddings hydraulic soil sampling machine. The wet treated plot received a 50 mm PVC access tube using a 50 mm OD soil density sampling tube attached to the Giddings apparatus. The semi-wet and dry plots received 50 mm PVC access tube using a 54 OD mm diameter sampling tube.

Throughout the summer of 1993, soil moisture in the above mentioned plots was monitored simultaneously using three techniques: gravimetric, neutron thermalization and capacitance. Gravimetric soil samples were manually taken at 15 cm intervals, 30 cm away from the PVC access tube center, using a 50 mm diameter auger. The sampled soil was taken at parallel depths of the neutron and capacitance probe readings. Troxler* Sentry model 200 AP capacitance probe was used for capacitance measurements. Frequency shift differences were obtained by using the Sentry 200 probe in conjunction with a Troxler* Probe Reader Plus multiplexer coupled to a portable IBM compatible computer.

At the Water Management Research Laboratory, Fresno, California a 1 m^3 wooden box was constructed and packed with a sandy loam soil to a density of 1.5 g/cm^3. A 50 mm PVC schedule 40 access tube for neutron and capacitance readings was installed during the back-filling. A surface drip system consisting of three 4L Hr^{-1} emitters was used to irrigate the soil surface. Four irrigations were applied to the boxed soil and were monitored with neutron and capacitance probes before, during and after irrigations to observe absorption and soil water movement. Gravimetric soil samples were taken in 10 cm intervals before, during and after each irrigation.

RESULTS: Statistical relationships for capacitance probe frequency differences (D values) versus true volumetric soil moisture are presented in Table 1. Derived data from the three different calibration equations began to approach impossible volumetric soil moisture at shallower depths (<23 cm). Neutron data obtained in the dry plot followed true

Table 1. Relationship of Sentry 200 AP capacitance probe D values to volumetric soil moisture of field and repacked soils.

Type of calibration	Field soil (clay loam)	R value	Repacked soil (sandy loam)	R value
Linear	$Y=0.028x-96.7$	0.89	$Y=0.033x-117.7$	0.97
Exponential	$Y=0.0015e^{0.0023x}$	0.93	$Y=0.0001e^{0.0003x}$	0.99
Factory	$Y=-26.8 \ln \frac{(x-4811)}{-1914}$	n.a.	$Y=-26.8 \ln \frac{(x-4811)}{-1914}$	n.a.

volumetric soil moisture trends, yet were positive.

Capacitance data from the semi-wet plot showed all three calibrated readings approach impossible to low volumetric soil moisture in the top 40 cm depth. The factory and exponentially calibrated capacitance data was exaggerated to unrealistic levels. Linearly calibrated capacitance data began to follow real volumetric soil moisture well throughout the profile only after the 40 cm depth.

The wet plot had its PVC access tube installed using the smaller diameter soil sampling tube thus creating the tightest soil-to-tube contact of all three treatments. Linearly calibrated capacitance data followed both neutron and real volumetric soil moisture patterns throughout the soil profile.

In the repacked soil study, both linearly and exponentially calibrated data from the repacked soil study had higher correlations than field capacitance data. Again, as in the field study, calibrated data from all three equations displayed drier readings in the upper 30 cm of the soil profile, yet in the repacked soil study, no data portrayed impossible volumetric soil moisture.

FUTURE PLANS: The Sentry 200 AP will be calibrated with the Sentek capacitance probe for bulk density, soil type and salinity considerations. Possible use in the Parlier dual lysimeters is scheduled.

EFFECT OF DEFICIT IRRIGATION ON N, P, K PARTITIONING IN SUBSURFACE DRIP IRRIGATED COTTON UNDER HIGH YIELD CONDITIONS

R.B. Hutmacher, C.J. Phene, K.R. Davis, S.S. Vail, A. Bravo, T. Pflaum, D. Ballard, M.S. Peters, C.A. Hawk, D.A. Clark, A. Nevarez, N. Hudson

OBJECTIVES: Subsurface drip irrigation studies at the U.C. West Side Research and Extension Center over the past three years have investigated Acala cotton responses to irrigation amounts ranging from mild to moderate deficit irrigation. These irrigation treatments, when combined with direct injection of nitrogen, phosphorus, and potassium fertilizers in the irrigation water, have resulted in lint yields in excess of 1900 kg ha^{-1} (1991 and 1992) and 1750 kg ha^{-1} (1993). Since these yields were high in comparison to the San Joaquin Valley average lint yield, we determined that it would be important to assess nutrient uptake associated with high yield conditions.

PROCEDURES: For details of basic procedures used in analyzing plants for nutrient uptake, cultural management and drip system operation, see report entitled "N, P, and K uptake in subsurface drip irrigated cotton under high yield conditions: N, P, K accumulations at peak total dry matter" elsewhere in this volume.
Accumulations of N, P, and K in above-ground tissues were evaluated several times per season in each of the three previous years in six different irrigation treatments on the Acala variety "GC510", and on three irrigation treatments in each of the experimental varieties "Columnar C1" and Pima variety "S6". Reference evapotranspiration from a large weighing grass lysimeter located in an adjacent field and a crop coefficient determined in 1980 and 1981 were used in irrigation scheduling. The calculated crop evapotranspiration (ETc) was multiplied by specific percentages during different periods of the growing season to provide different degrees of deficit irrigation during specific periods.

The periods of initiation of drip irrigation treatments differed some between 1991, 1992, and 1993, but the following generalizations apply: T1 = irrigations to supply 100% of ETc the entire growing season; T2 = 100% of ETc through late July followed by 80% ETc the rest of the season; T3 = same as T2 except 60% ETc during the late season; T4 = 100% ETc through early July, followed by 80% ETc through early August followed by 60% ETc irrigations the rest of the season; T5 = 100% ETc through early July followed by 80% ETc the rest of the season; T6 = 100% ETc through early July followed by 60% ETc the rest of the season.

RESULTS AND DISCUSSION: Accumulation of total N, P, and K in above-ground tissues was quite similar across varieties during the first two years of the study and about ten percent lower during the third season. The total mass of nutrients accumulated was significantly influenced by irrigation treatments. Generally, reduced accumulations of N, P and K in more severe water deficit treatments (60% ETc treatments such as treatment T6) were mostly associated with reductions in total leaf and stem dry matter associated with reduced overall vegetative growth, not with reductions in tissue N (Fig. 1), and P or K (data not shown) concentrations. Tissue N, P and K concentrations at the final measurement date in September (data shown for N in Fig. 1) or early and mid-season dates were either unaffected or even slightly increased with more severe deficit irrigation.

Reproductive tissue nutrient concentrations were also relatively consistent within each variety on each measurement date (data not shown), therefore, differences in total plant N, P, and K uptake across irrigation treatments (Fig. 2) tended to reflect mostly differences in leaf and stem dry weight.

FUTURE PLANS: This data when compiled and summarized will provide some of the only information on nutrient uptake (as a function of plant growth stage) for modern cotton varieties grown under high-yield conditions. This information will be presented in part at the 1995 Microirrigation Conference and Cotton Production Research Conference, and a manuscript will be prepared.

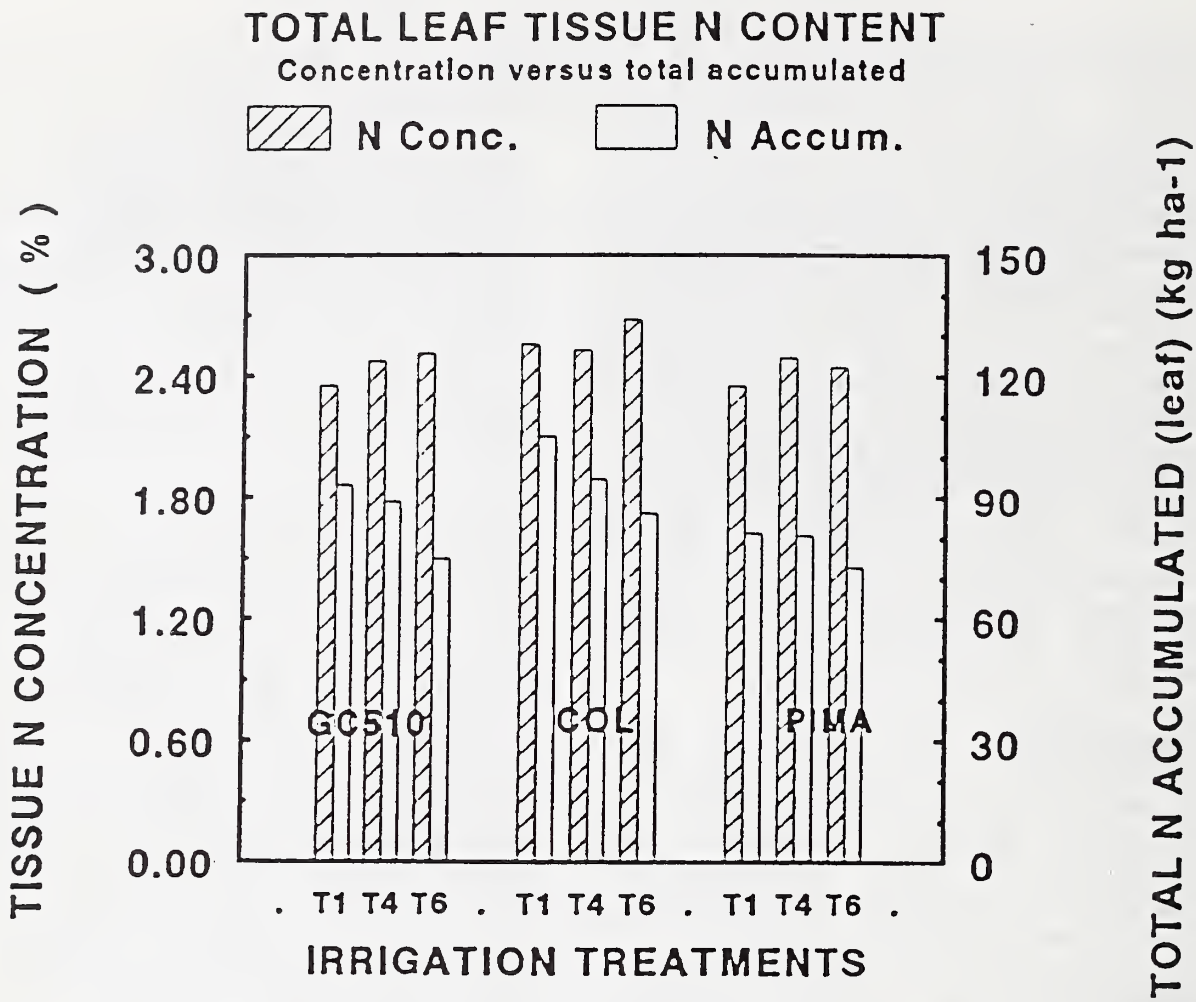


Figure 1. Average leaf tissue nitrogen (N) concentration ("N Conc.") and total N accumulated in all leaf tissué ("N Accum.") at early–September sampling date for GC510, Columnar (COL) and Pima varieties for irrigation treatments T1, T4, T6. Data shown represents averages over two year period in subsurface drip irrigated cotton at the West Side Research and Extension Center near Five Points, CA.

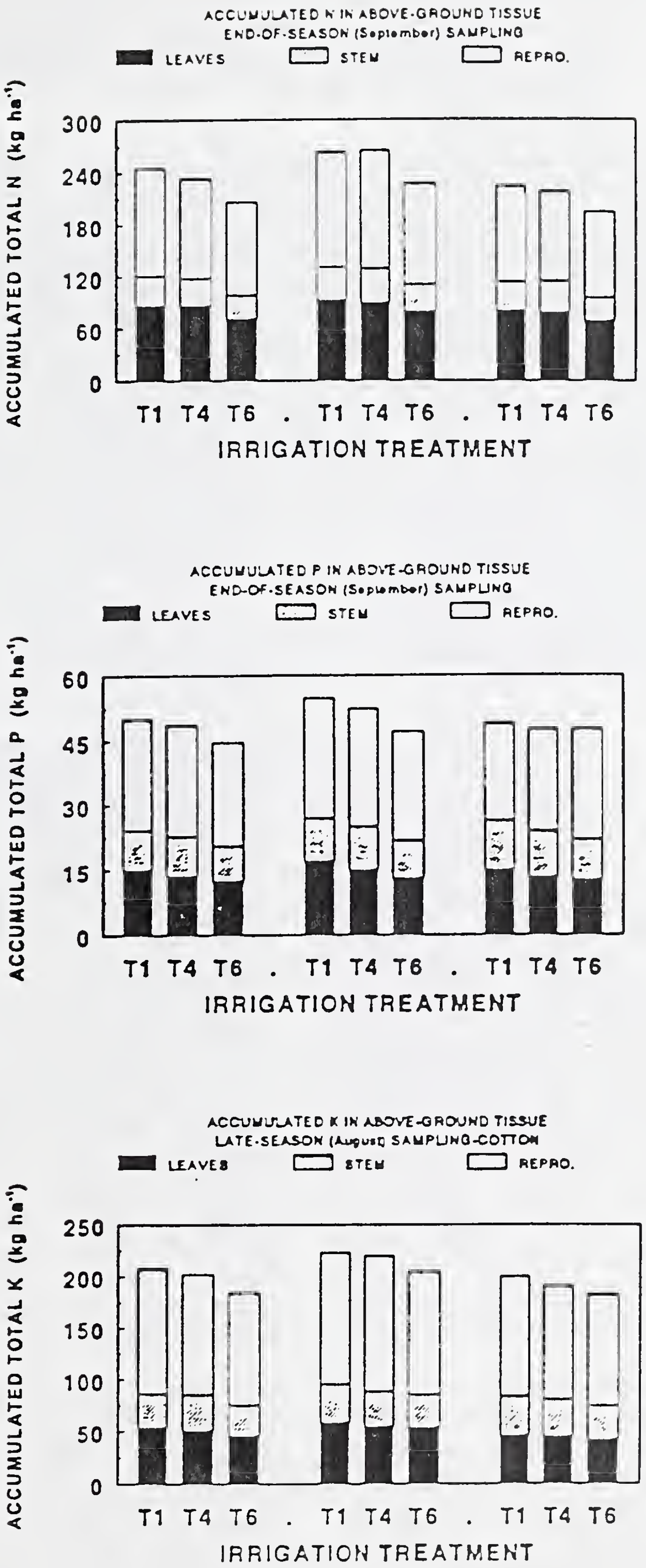


Figure 2. Nutrient amounts accumulated (A) nitrogen, (B) phosphorus, and (C) potassium in all above-ground cotton tissue for irrigation treatments T1, T4, and T6 averaged over a two year period. Data collected in plants grown at the West Side Research and Extension Center near Five Points, CA.

MACRONUTRIENT UPTAKE IN SUBSURFACE DRIP IRRIGATED COTTON UNDER HIGH YIELD CONDITIONS

R.B. Hutmacher, C.J. Phene, K.R. Davis, S.S. Vail, A. Bravo, T. Pflaum, D. Ballard, M.S. Peters, C.A. Hawk, D.A. Clark, A. Nevarez, N. Hudson

OBJECTIVES: Subsurface drip irrigation studies at the West Side Research and Extension Center over the past three years have investigated Acala cotton responses to irrigation amounts ranging from mild to moderate deficit irrigation. These irrigation treatments, when combined with direct injection of nitrogen, phosphorus, and potassium fertilizers with the irrigation water, have consistently resulted in lint yields in excess of 1900 kg ha^{-1} (1991 and 1992) and 1750 kg ha^{-1} (1993). Since these yield levels were consistently high in comparison with San Joaquin Valley average lint yields, we determined that it would be useful to assess nutrient uptake associated with high yield conditions.

PROCEDURES: Cotton was grown in 0.76 m beds in a Panoche clay loam soil in 1991, 1992, and 1993. The subsurface drip line was 45 cm deep and 1.52 m apart under alternate furrows. Six subsurface drip irrigation treatments were imposed on Acala (var. GC510) and Pima (var. S6) cotton, with the irrigation treatments representing combinations of different water application rates (60%, 80%, or 100% of estimated crop evapotranspiration (ETc)) and different timing of deficit irrigation (pre-flower, during flowering, during boll-filling). Peak lint yields were achieved with 700 to 760 mm ETc. See accompanying report entitled, "Effect of Deficit Irrigation on N, P, K Partitioning in Subsurface Drip Irrigated Cotton", elsewhere in this volume for another report related to nutrient accumulation.

Nitrogen was applied through the drip systems as calcium ammonium nitrate during June and July and as potassium nitrate during August, while phosphorus was applied in the irrigation water using phosphoric acid. Total N, P, and K applications were similar across the three years, with 212, 83 and 111 kg ha^{-1}, respectively in 1991, 203, 84, and 126 kg ha^{-1} in 1992, and 205, 87 130 kg ha^{-1}, respectively, in 1993.

Deficit irrigation practices, in combination with conservative nutrient applications, proved effective in managing crop vegetative growth, while achieving high yields. Nutrient uptake was monitored in several irrigation treatments as a function of growth stage. Petiole nutrient levels were monitored using weekly samples, while above-ground plant nutrient uptake was determined on five-plant subsamples from each measured treatment, with three to five sampling dates per year. Abscissed leaves and reproductive tissue were included with above-ground tissue analyzed for nutrient content.

RESULTS / DISCUSSION:

Petiole Nutrient Status. There were no significant interactions between irrigation treatments and petiole nutrient status in NO_3-N, P or K (Fig. 1). Early-season petiole NO_3-N levels in Acala and Pima varieties were generally lower than University of CA recommendations for Acala varieties, while mid- and late-season values were generally within recommended levels. Petiole NO_3-N levels of the Pima variety were significantly lower than in the Acala types (particularly prior to day 210) despite identical nutrient applications. Petiole P and K levels were not significantly different between Acala and Pima varieties. In all treatments, PO4-P levels were consistently 10 to 15% lower than University of California recommendations for Acala varieties.

Soil Nutrient Status and Plant Nutrient Uptake. Soil N analyses indicated that low soil NO_3-N and total N levels prevailed before and after each season (ie. 5-25 mg NO_3-N kg^{-1} soil in upper 45 cm soil, < 3 mg/kg in the 45 to 210 cm depths), indicating relatively low potential for large amounts of N carryover from prior crops. Soil PO_4-P levels were also quite low throughout the soil profile.

Above-ground N, P and K accumulations (for all above-ground tissue in mid-September) expressed per unit lint yield averaged 10.9, 2.4, and 9.3 kg/100 kg lint, respectively (Table 1). These accumulations per unit lint yield are generally 20 to 40% lower than measured by other researchers under low to moderate yield conditions (including prior recommendations for Acala varieties in the San Joaquin Valley) but are in basic agreement with results under high yield conditions in Israel. These results suggest significant potential for higher nutrient use efficiency using subsurface drip irrigation under San Joaquin Valley conditions, and also indicate the need to reassess assumed nutrient requirements under high yield conditions with new varieties.

Table 1. Amount of nutrient (nitrogen (N), phosphorus (P) or potassium (K)) contained in above-ground plant tissue at mid-September harvest date per 100 kg lint yield as a function of year and variety. Values shown are an average across all irrigation treatments within each variety. Plant samples for nutrient analyses were collected one to two weeks prior to defoliant applications.

Year	Variety	N in above-ground tissue (kg per 100 kg lint)	P in above-ground tissue (kg per 100 kg lint)	K in above-ground tissue (kg per 100 kg lint)
1991	GC510	9.5	2.2	8.7
	Pima S6	10.0	2.4	9.4
1992	GC510	11.0	2.3	8.8
	Pima S6	11.5	2.6	9.3
1993	GC510 [z]	12.1	2.2	9.5
	Pima S6 [z]	12.7	2.5	10.1

[z] results from 1993 only for 100% ETc treatment.

FUTURE PLANS: A paper has been prepared for both the 1995 Cotton Production Research Conference and the 1995 Microirrigation Congress. Additional plant analyses are continuing in order to develop crop uptake patterns as a function of growth stage.

NITROGEN MANAGEMENT OF COTTON UNDER SUBSURFACE DRIP IRRIGATION - IDENTIFICATION OF CRITICAL NITROGEN LEVELS: I. OPERATIONAL PROCEDURES

R.B. Hutmacher, C.J. Phene, S.S. Vail, T.A. Kerby, M.S. Peters, C.A. Hawk, M. Keeley, A. Bravo, T. Pflaum, D.A. Clark, D. Ballard, N. Hudson

OBJECTIVES: This drip irrigation experiment is part of a three to five year cooperative project with University of California Extension staff. The long-term goal is to identify growth-stage-specific levels of plant and soil nitrogen under specific management practices and their relationships to specific physiological processes, growth and yield limitations. Other projects associated with this drip project are investigating methods to split fertilizer applications using surface irrigation rather than drip irrigation.

The subsurface drip system is being used in this portion of the study to deliver precise amounts of nitrogen fertilizer over time and to identify plant responses to different severities and timing of nitrogen deficits.

PROCEDURES: *Irrigation System.* Cotton (var. "Maxxa") was planted on JD 106 (April 16, 1993). Mepiquat chloride (PIX) was applied uniformly to all plots at a rate of 0.9 L ha^{-1} on July 8, 1993 (JD 189). The drip laterals were spaced 1.52 m apart under alternate furrows and 45 cm below the average soil surface. Drip emitters (turbulent-flow, in-line design) were spaced 0.91 m apart along the laterals, and had a nominal flow of 2 L h^{-1} at 120 to 140 kPa operating pressure. Each plot consisted of 12 rows spaced 0.76 m apart and 9.3 m in length.

Plant water status resulting from irrigation treatments was monitored using a crop water stress index (CWSI) approach using an infrared thermometer and hand-held psychrometer. Measurements of crop water status were made at one week intervals throughout the season.

An average of 521 mm of irrigation water was applied to all treatments during the growing season. Calculated crop evapotranspiration (including measured soil water depletion) averaged 725 mm for the growing season, and ranged from a low of 678 mm in the no nitrogen treatment to over 770 mm in a high nitrogen treatment (see below for treatment descriptions).

N Fertilizer Treatments. The nine fertilizer treatments included one control with no N added (T1), and combinations of patterns of N application (linear (T8 and T9) versus growth-stage and uptake rate-dependent (T2 through T7)). Target amounts of applied N were 60 (T2 and T5), 120 (T3 and T6), 180 (T4, 7, 8, 9) kg N ha^{-1}. Actual N amounts applied 67 kg N ha^{-1} (T2 and T5), 134 kg N ha^{-1} (T3 and T6), 202 kg N ha^{-1} (T4, 7, 9) and 118 kg N ha^{-1} (T8). T8 did not receive the full amount proposed due to a late start in injecting the fertilizer. Nitrogen applications in T8 were all made between day 180 and 193, while applications in T9 were made between day 187 and 221. All other treatments commenced N applications on day 180 and ended day 242. An additional, 56 kg N ha^{-1} was applied prior to planting in treatments 5 through 9. All N fertilizer treatments were replicated four times and N was applied using a venturi-type injector. Potassium thiosulphate was applied once per week (and separate from the phosphoric acid application) to supply potassium fertilizer (205 kg K ha^{-1} to all treatments) needs. Phosphoric acid and calcium ammonium nitrate were used to apply phosphorus and nitrogen, respectively. A total of 71 kg P ha^{-1} was applied uniformly to all treatments.

Soil Sampling. Soil samples were collected after seedling emergence in 22.5 cm increments to 90 cm and 30 cm increments from 90 to 270 cm to a depth of 3 m to establish initial soil nutrient and salinity levels in each block of the field. Additional samples were collected to a depth of 3m within 3 weeks after harvest. All samples will be analyzed for soil water content, electrical conductivity, pH, NO_3-N, P, K, Total N, and Cl.

Plant Sampling - Nutrients, Growth, Yield. Plant Sampling - Nutrients, Growth, Yield. Petiole samples from the most recent fully-expanded leaves were collected weekly and analyzed for NO_3-N, PO_4-P, and K. Above-ground plant samples were collected three times during the growing season to identify above-ground nutrient uptake based upon the average tissue nutrient concentrations and dry matter sampling of component plant parts. Main stem and sympodial leaves at different positions within the canopy were sampled at intervals through the season and analyzed for gas exchange rates, total-N, chlorophyll levels, and incident radiation at different levels within the crop canopy. Plant growth and development were monitored as plant height, node counts, nodes above white bloom, boll counts and position, plant leaf area, and dry matter partitioning. Plots were machine harvested on JD 312 with a modified commercial spindle picker and seed cotton yields were determined on two rows per plot. Gin turnout was determined at the USDA-ARS Cotton Laboratory in Shafter, CA.

RESULTS AND DISCUSSION: See accompanying reports for details of results on plant gas exchange, water relations, petiole nutrient levels and growth and yield responses.

NITROGEN MANAGEMENT OF COTTON UNDER SUBSURFACE DRIP IRRIGATION: II. LEAF N AND CHLOROPHYLL METER CORRELATIONS

R.B. Hutmacher, C.J. Phene, S.S. Vail. T.A. Kerby, D. Ballard, M.S. Peters, C.A. Hawk, A.D. Bravo

OBJECTIVES: This subsurface drip irrigation experiment is part of a series of three to five year cooperative projects with the University of California Cooperative Extension with the long-term goal of identifying growth-stage specific levels of nitrogen (N) and their relationships to specific physiological functions, growth and yield limitations. For more details, see report entitled: "Nitrogen Management of Cotton under Subsurface Drip Irrigation - Identification of Critical N Levels: Operational Procedures" elsewhere in this volume.

Chlorphyll fluorescence (determined with a Minolta Spadmeter) has been used successfully with a number of grain crops (corn, rice) as a relative indicator of leaf nitrogen status, with lower chlorophyll fluorescence levels indicating reduced tissue total N status. One major potential advantage of this method is that it is non-destructive. One objective in the current study is to evaluate leaf N levels in a variety of leaf positions (representing different leaf ages and positions) as a function of N fertilizer treatments. Presumably, severe N deficits in monopodial or sympodial leaves would reduce photosynthetic capacity and be detrimental to boll production and filling. Since it is laborious to collect leaves and run Kjeldahl analyses for total N, it would be desirable to evaluate a non-destructive method for N evaluation in cotton.

PROCEDURES: A Minolta Spadmeter was used for leaf chlorophyll fluorescence measurements. Chlorophyll measurments were made on leaves at positions (relative to the uppermost main stem node) of nodes 3, 5, 8, 11 and the first and second sympodial positions on a sympodial branch originating at the 11th node from the most recent. Measurements were replicated on three subsample plants in each of three blocks of each fertilizer treatment. Leaf samples were taken from select nodes and analyzed for total N to develop a correlation between leaf N and chlorophyll meter readings. For details on cultural practices and experimental design see report entitled: "Nitrogen Management of Cotton under Subsurface Drip Irrigation - Identification of Critical N Levels: Operational Procedures" elsewhere in this volume.

RESULTS / DISCUSSION: The different N treatments (including the no applied N treatment) did not consistently and significantly affect the chlorophyll fluorescence readings on most measurement dates, even during the months of August through mid-September (data not shown). Studies were focused on these periods due to the declining photosynthetic capacity of the leaves during the boll filling and period of cessation of vegetative growth. During this same period, petiole NO_3-N and leaf total N declined significantly and differences between low N or no N treatments and the higher N treatments became more pronounced (data not shown).

It was somewhat surprising that the chlorophyll meter readings were not able to reflect some of the differnces apparent in leaf N status. Chlorophyll meter readings were generally within the 45 to 60 range (relative units), indicating high fluorescence levels (and at least moderately high N levels in other plant species).

Leaf position significantly affected chlorophyll fluorescence readings on many measurement dates (data not shown), with the highest readings consistently in the third leaf node from the uppermost main stem node, an intermediate level in the fifth and sixth node position and sympodial leaves, and the lowest fluorescence readings in the eighth and eleventh main stem node positions. Leaf total N (determined by Kjeldahl analyses) were not significantly correlated (positively or negatively) with the fluorescence readings. The highest leaf N levels were

generally in the fifth and eighth node leaves (counted from the top main stem node), followed by the sympodial leaves (if they were in a well-illuminated position), and were lowest in main stem node positions either at the upper part of the canopy (immature leaf at 3rd node from the top) or in the poorly illuminated lower main stem leaves (11th node from the top).

Average leaf total N levels were significantly lower in no N and low N treatments in the August through September period, and were correlated with reduced net photosynthetic capacity in low N treatments.

FUTURE PLANS: This study is planned to continue for at least three years after the 1993 season, with emphasis on determining any relationship between petiole NO_3-N, leaf N and gas exchange responses. Due to the inconsistent chlorophyll meter readings and the lack of a good correlation with leaf total N or petiole NO_3-N, the chlorophyll meter readings will be discontinued in the present study. Greenhouse or container plant studies will be used to evaluate the potential utility of these measurement methods on other species.

NITROGEN MANAGEMENT OF COTTON UNDER SUBSURFACE DRIP IRRIGATION: III. LEAF GAS EXCHANGE

R.B. Hutmacher, C.J. Phene, S.S. Vail. T.A. Kerby,
M.S. Peters, C.A. Hawk, A.D. Bravo, D.A. Clark

OBJECTIVES: This subsurface drip irrigation experiment is part of a series of three to five year cooperative projects with the University of California Cooperative Extension Service with the long-term goal of identifying growth-stage specific levels of nitrogen (N) and their relationships to specific physiological functions, growth and yield limitations. For details on experimental design and operation, see report entitled: "Nitrogen Management of Cotton under Subsurface Drip Irrigation - Identification of Critical N Levels: Operational Procedures" in this volume.

PROCEDURES: Leaf abaxial and adaxial resistances and transpiration rates were monitored at 7 to 14 day intervals at specific leaf positions using a Li-Cor 1600 series steady-state porometer. Incident photosynthetic photon flux density (PPFD) was monitored for each leaf studied, and only leaves with PPFD levels in excess of 1200 umoles m^{-2} s^{-1} were used in this analysis.

Single leaf photosynthetic rates were determined at 7 to 14 day intervals using an ADC infrared gas analyzer and Parkinson leaf chamber in the flow-through mode with a constant flow rate of 0.6 L min^{-1}. The third, fifth or sixth, and eighth or ninth leaf from the uppermost node were monitored in order to determine the relative sensitivity of leaves of different stages of maturity and different ages to the imposed N fertilizer treatments. Only results collected from the first fully-expanded recently mature leaf (fifth or sixth leaf from the uppermost node) will be discussed. However, general findings for the fifth or sixth leaf also apply to the other leaf ages. For more details of plant responses, see other reports in this series.

RESULTS / DISCUSSION: On any measurement dates, leaf conductances were not significantly affected by any nitrogen treatment (data not shown). Prior studies done in Arizona suggest that severe N deficits result in reduced leaf conductance (similar to a water deficit response), but petiole NO_3-N levels in those Arizona studies were significantly lower than in the no N and low N treatments in the current study (see data presented elsewhere in this volume). Leaf age was much more a determinant of leaf conductance, with the highest and most variable conductance in the youngest leaves (third node from the top of the plant), intermediate at the sixth node down, and lowest in the older leaves at the eighth or ninth node from the top.

Net photosynthetic rates were significantly reduced starting in mid-July in the no N treatment (treatment #1 (data not shown)) and in late July in the low N treatments (treatment #5 (Fig. 1)) even when a pre-plant N fertilizer was applied.

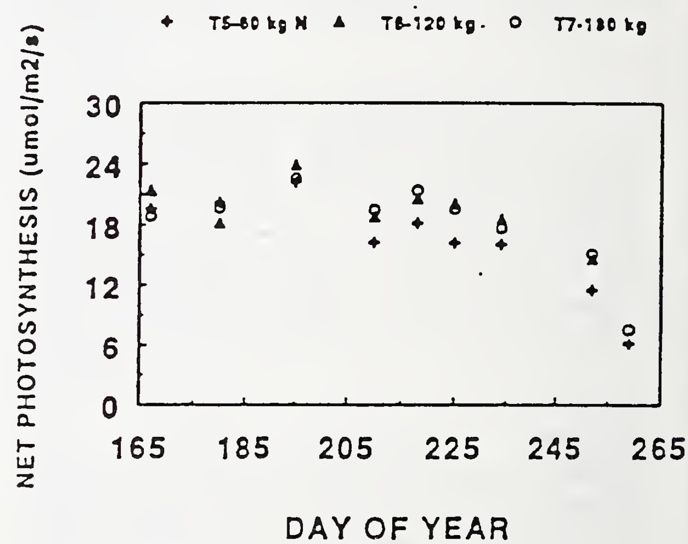


Figure 1. Leaf net photosynthetic rates for the sixth leaf from the uppermost node as a function of day of the year and nitrogen fertilizer treatment. Data collected is from the 1993 cotton project at the West Side Research and Extension Center near Five Points, California.

Photosynthetic rates declined an average of 10 to 16% (depending on the measurment date) in the low N treatments. This period

of reduced net photosynthetic activity in upper canopy leaves may reflect reductions in leaf soluble protein occurring with reduced N-availability.

If reductions in photosynthetic capacity occur relatively late in the season (when bolls are relatively mature and carbohydrate demands are low), the affect on lint yield would be expected to be minimal. If, however, the reductions in photosynthetic capacity occur with a late boll set, reduced photosynthetic capacity should be more important in being a partial cause of reduced yields. Data from this first year indicates that reduced N applications in the moderate N treatments did not reduce plant N levels sufficiently to influence net photosynthesis. The relative importance of stored soil N in providing N to avoid deficits in moderate N application treatments has not been established at the time of this report.

Photosynthetic rate reductions were not caused by reductions in leaf conductance, but rather were due to nonstomatal limitations, resulting in significantly lower net photosynthesis per unit leaf conductance in the no N treatment (data not shown) and low N treatments (treatment #5 shown in Fig. 2). This reduction was particularly accentuated during the period of rapid boll development.

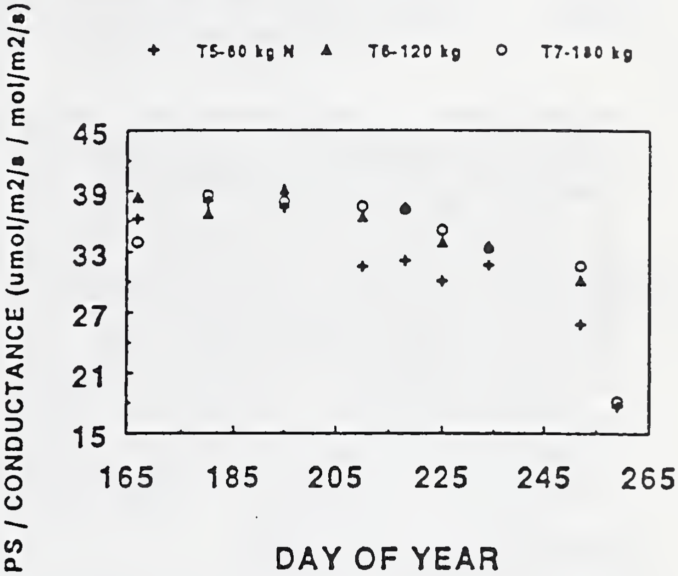


Figure 2. Leaf net photosynthesis per unit leaf conductance for the sixth leaf from the uppermost node as a function of day of the year and nitrogen fertilizer treatment. Data shown is from the 1993 cotton project at the West Side Research and Extension Center near Five Points, California.

<u>FUTURE PLANS</u>: This study is planned to continue for at least three years after the 1993 season, with emphasis on determining any relationship between petiole NO_3-N, leaf N and gas exchange responses.

NITROGEN MANAGEMENT OF COTTON UNDER SUBSURFACE DRIP IRRIGATION: IV. PETIOLE NUTRIENT STATUS

R.B. Hutmacher, C.J. Phene, S.S. Vail. B. Weir, K.R. Davis, R. Vargas. M. Keeley, T.A. Kerby, T. Pflaum, M.S. Peters, C.A. Hawk, A.D. Bravo, D.A. Clark

OBJECTIVES: This subsurface drip irrigation experiment is part of a series of three to five year cooperative projects with the University of California Cooperative Extension Service with the long-term goal of identifying growth-stage specific levels of nitrogen (N) and their relationships to specific physiological functions, growth and yield limitations. For details, design, and operation, see report entitled: "Nitrogen Management of Cotton under Subsurface Drip Irrigation - Identification of Critical N Levels: Operational Procedures" in this volume.

PROCEDURES: Petiole samples were collected at 7 to 10 day intervals throughout the season and dried at 50 to 55 degrees C for a minimum of 48 hours prior to grinding and analysis. A minimum of 25 petiole samples were collected per treatment block from separate plants at the uppermost fully-expanded leaf node. For more details of plant responses, see other reports in this series.

RESULTS / DISCUSSION: The most significant reductions in petiole NO_3-N were observed consistently in the untreated control (no nitrogen treatment, treatment #T1) and in the low nitrogen treatments (treatment #2 (without pre-plant N application) and treatment #5 (with pre-plant N application)) (Fig. 1). At any of the N fertilizer application levels (low, medium, high), there were no consistent differences in petiole NO3-N associated with the pre-plant N application (Fig. 1). The only differences occurred between treatments #3 (no pre-plant N) and #6 (pre-plant N) at the moderate N application level, but this only occurred from mid-July through mid-August. Treatment #9, with N applications begun in mid-season, did not exhibit significantly higher petiole NO_3-N until late in the season.

In this first year of the study, petiole NO_3-N levels in all but the no N or low N treatments (#1, #2, and #5) remained within the University of CA recommended petiole NO_3-N levels during all growth stages. Since cotton yields were high (> 2200 kg ha^{-1}) in all but the no N treatment, the lack of major petiole NO_3-N response to pre-plant supplemental N also suggests that high cotton yields could be achieved at far less than the 180 kg N ha^{-1} typically applied to high-yield cotton production areas. Proper interpretation of this petiole nutrient and yield data will require analysis of soil samples to identify residual soil N that can also be available in meeting crop N requirements. Soil samples have been taken prior to and after the initial growing season, but chemical analyses have not been completed at the time of this report.

There were no significant and consistent interactions between N treatments and petiole PO_4-P or K levels, with PO_4-P and K levels consistently within the University of CA recommended petiole levels for each growth stage.

FUTURE PLANS: Whole-plant samples taken at four or five sample dates in each treatment were partitioned into stem, leaves, and reproductive components; and await chemical analysis. Plant nutrient uptake tissue nutrient concentrations will be compared with petiole nutrient data. This study is planned to continue for at least three years after the 1993 season.

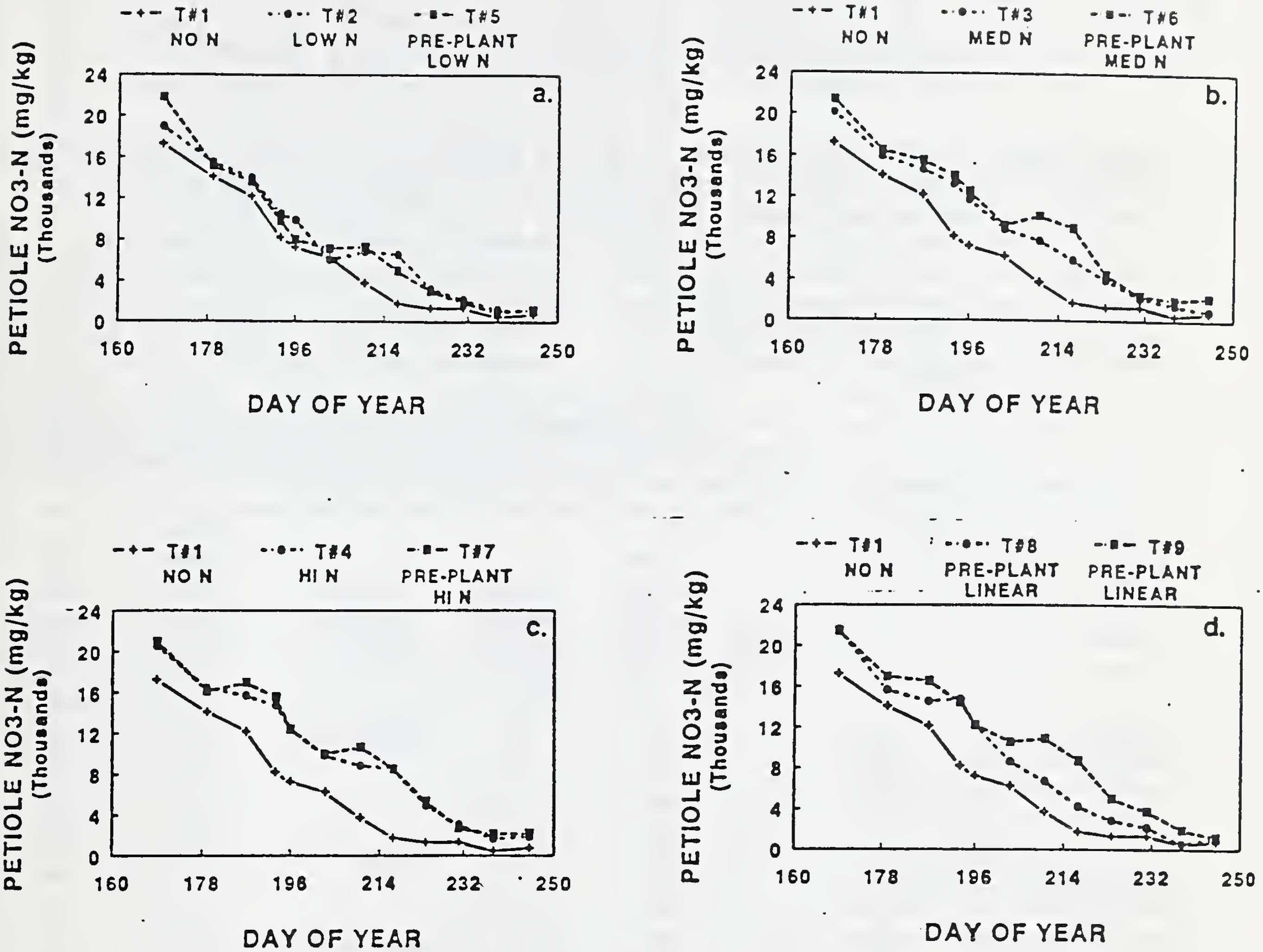


Figure 1. Cotton petiole NO3–N means as a function of day of year and nitrogen treatment in cotton grown in a Panoche clay loam soil at the West Side Research and Extension Center near Five Points, CA in 1993. Treatments are identified in legends of Fig. 1A through 1D.

NITROGEN MANAGEMENT OF COTTON UNDER SUBSURFACE DRIP IRRIGATION: V. GROWTH AND YIELD RESPONSES

R.B. Hutmacher, C.J. Phene, S.S. Vail. B. Weir,
K.R. Davis, R. Vargas. M. Keeley, T.A. Kerby, T. Pflaum,
M.S. Peters, C.A. Hawk, A.D. Bravo, D.A. Clark

OBJECTIVES: This subsurface drip irrigation experiment is part of a series of three to five year cooperative projects with the University of California Cooperative Extension Service with the long-term goal of identifying growth-stage specific levels of nitrogen (N) and their relationships to specific physiological functions, growth and yield limitations. For more details, see report entitled: "Nitrogen Management of Cotton under Subsurface Drip Irrigation - Identification of Critical N Levels: Operational Procedures" in this volume.

PROCEDURES: Plant height and node counts were done in each treatment at 7 day intervals. Leaf area index and partitioning of total plant above-ground dry matter was done four times during the growing season. Yields were determined using a modified commercial spindle picker and corrected for moisture content and gin percentage. For more details of plant responses, see other reports in this series.

RESULTS / DISCUSSION: Plants in the treatment not receiving any nitrogen were significantly shorter than all other treatments by early-July, while the low N treatments (treatments #2 and #5) were significantly shorter by later in July. Individual leaf expansion rates and the number of main stem nodes and the extension of sympodial branches were significantly reduced in treatments #1 and #2, and these parameters were generally reduced by between 8% and 15%. Nodes above white bloom (as an indicator of plant maturity and vegetative cutout) indicated a significantly more rapid progression toward cutout only in treatment #1.

In mid-August (data not shown) and mid-September, total above-ground plant dry matter (Table 1) and leaf area index (Table 1) were significantly lower in treatments #1, #2, and #5 (no N and low N treatments, respectively) when compared with all other treatments, indicating a significant reduction in overall growth with no or low N treatments. Within any level of within-season N application, there were no significant differences in growth responses to pre-plant N versus no pre-plant N.

Table 1. Total above-ground plant dry matter (as of September 21) and leaf area index (as of August 24) of all cotton N treatments at the West Side Research and Extension Center near Five Points, CA in 1993.

Trt. Number	Within-season N applied (kg ha^{-1})	Pre-plant N applied (kg ha^{-1})	Nitrogen application pattern	Total above-ground dry wt. (Mg ha^{-1})	Leaf area index (m^2/m^2)
1	0	0	-	14.8	4.07
2	60	0	uptake curve	15.5	4.37
3	120	0	" "	17.4	4.77
4	180	0	" "	18.1	5.03
5	60	56	" "	15.3	4.35
6	120	56	" "	18.4	4.86
7	180	56	" "	18.5	5.24
8	180	56	linear(nodes 5-10)	17.2	4.68
9	180	56	linear(nodes 11-16)	17.4	4.73

Lint yields were quite high in all treatments, with yields generally in excess of 2200 kg lint ha^{-1} in all treatments other than treatment #1 (no N) (Fig. 1). Treatment #1 (no N) had a significantly lower yield than all treatments. other than treatment #2 (low N, no pre-plant N). A general trend existed toward slightly lower yields under the low N treatments, and no change in yields at N applications above the moderate N treatments. The question

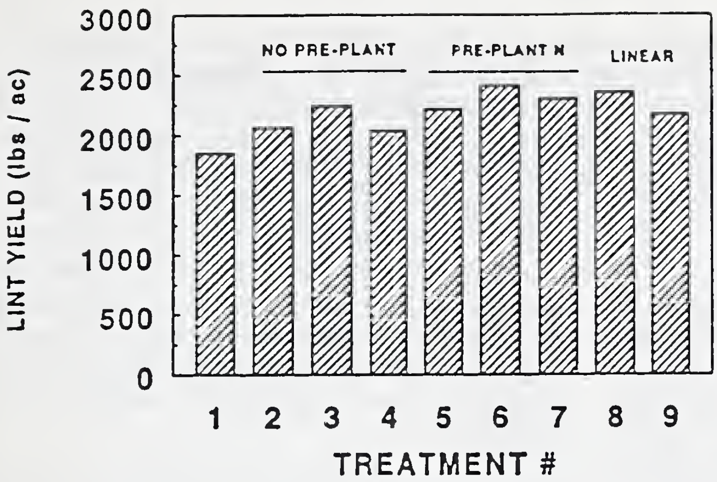


Figure 1. Lint cotton yield from November, 1993 harvest of nitrogen experiment at the West Side Research Extension Center near Five Points, California.

of whether or not these high yields could be sustained with such low N applications on a continuing basis will partly be answered when soil samples can be analyzed to determine relative levels of soil N available as residual soil N.

FUTURE PLANS: This study is planned to continue for at least three years after the 1993 season.

DRIP LATERAL INSTALLATION DEPTH: EFFECTS ON CROP GROWTH, YIELD, NUTRIENT UPTAKE AND SOIL WATER AND SALINITY DISTRIBUTION

R.B. Hutmacher, C.J. Phene, K.R. Davis, D.A. Clark, M. Rehan, R.M. Mead, C.A. Hawk, M.S. Peters, A. Bravo, D. Ballard, N. Hudson

OBJECTIVES: Determine the influence of subsurface drip lateral installation depth on: (1) growth and yield of annual crops; (b) salinity and water distribution within the soil profile (vertical and lateral distribution) relative to emitter locations; and (c) crop nutrient uptake and distribution in the soil profile.

PROCEDURES: An experiment to investigate crop responses and water and nutrient uptake under different subsurface drip lateral placements was initiated at the University of California West Side Research and Extension Center near Five Points, California. The research site is in a Panoche clay loam soil, with no major restrictions to root development within the upper 2.5 m of soil. Subsurface drip laterals were installed at depths of 30, 45, and 60 cm with uniform 1.6 m lateral spacing and below the center of each 1.6 m bed. This field is also the site of a large (2m by 2m by 2.5m) weighing lysimeter which can be used to determine crop evapotranspiration. The drip lateral placement in the lysimeter is 45 cm deep. Irrigation water used in this field comes from either the California Aqueduct (0.6 dS m^{-1}) or from a well producing moderately saline water (1.7 dS m^{-1}). The water source depended on water allotments in the Westlands Irrigation District.

Each installation depth treatment, was further subdivided into of three secondary treatments of 3, 3 and 4 beds within each replication. These secondary treatments allow for consideration of water application amount or irrigation frequency treatments in addition to the drip lateral installation depth treatments.

RESULTS / FUTURE PLANS: During the 1993 season cotton (var. "Maxxa") was grown on this field and the three secondary treatments consisted of different application rates of the plant growth regulator "PIX" (mepiquat chloride). The results of the 1993 cotton evaluation are reported in "Direct injection of growth regulator PIX (mepiquat chloride) in drip irrigation water: effects on cotton" in this volume.

A very detailed soil sampling was led by Dr. M. Rehan during the 1993 cotton season to identify the effect of lateral depth on movement of phosphorus applied with continous injection of phosphoric acid during irrigation. Soil samples were collected four times during the growing season to assess changes as a function of cotton growth stage. Samples were collected in 22.5 cm increments to 90 cm and 30 cm increments to 270 cm at eight locations in a grid of 15 cm increments laterally from emitter positions. Crop nutrient uptake and development were also monitored periodically to match crop responses with measured soil nutrient levels. These analyses were incomplete at the time this report was prepared. Less-detailed soil nutrient analyses will be conducted as part of future studies.

Future studies will focus on evaluating the effect of lateral installation depth and irrigation amounts and/or frequency on maintenance of acceptable water, nutrient and salt levels within the crop root zone. In order for the drip lateral spacing and depths to be successful for long-term (5 to 10 year) use, it is desirable to have it deep enough to allow tillage operations while minimizing the number of drip lines required to be compatible with production of crops varying in rooting patterns and depth. A crop rotation that may include lettuce, broccoli, processing tomatoes and other crops will be used over the next several years to determine the degree to which water, nutrients and salinity can be effectively managed in crops with differing in rooting depth, time of maximum growth rate and duration of growing season.

Broccoli will be planted in September, 1994 as the first crop in this long-term crop rotation study. Three irrigation levels ranging from 0.6 to 1.4 times potential evapotranspiration will be used to evaluate water application amount effects on water, nutrient and salt movement and uptake. Soil matric potential sensors will be used in combination with a variety of methods to monitor soil water content to determine direction and relative patterns of soil water movement as a function of water application amount and lateral depth. Soil chemistry sampling will focus on movement and changes in salinity, chloride, and NO_3-N during each cropping season.

DIRECT INJECTION OF GROWTH REGULATOR PIX (MEPIQUAT CHLORIDE) IN DRIP IRRIGATION WATER: EFFECTS ON COTTON

C.J. Phene, K.R. Davis, R.B. Hutmacher, D.A. Clark,
M. Rehan, C.A. Hawk, M.S. Peters, D. Ballard, N. Hudson

OBJECTIVES: Determine the influence of direct injection of mepiquat chloride (trade name "PIX", BASF Corp.) on cotton growth and yield and the interactive effects of lateral installation depth on cotton response to mepiquat chloride.

PROCEDURES: Drip tubing was installed at the University of California West Side Research and Extension Center near Five Points, CA at depths of 30, 45, and 60 cm with uniform 64 cm lateral spacing. Drip lines were installed below the center of each 64 cm bed. Each lateral installation depth treatment plot consisted of 10 beds, 96 m in length, replicated 4 times. The soil at the site is a Panoche clay loam. Within each installation depth treatment, there was a further subdivision of three secondary treatments of 3, 3 and 4 beds each within each replication.

During the 1993 season, as a continuation of two previous years of experimentation with drip-injected mepiquat chloride, the three secondary treatments were used to evaluate cotton responses to injection of high dosage rates of mepiquat chloride. The growth regulator was injected into the irrigation water during a 10 mm irrigation, followed up within one to two hours with another 8 mm application of irrigation water to dilute and move the solution out from the point of application into the root volume. Application rates of 21.9 L mepiquat choloride ha^{-1} and 36.6 L ha^{-1} were tested and compared against a treatment with no mepiquat chloride (control). These application rates were based upon preliminary results from previous studies. The cotton (var. "Maxxa") crop was planted in April, 1993 and the growth regulator applications were made in July. Total fertilizer applications were the same in all treatments, totalling 190 kg N/ha, 103 kg P/ha and 92 kg K/ha. Drip applied water totalled about 75 mm prior to planting, 410 mm post-planting, while approximately 110 cm were applied by sprinkler prior to planting.

Plots were machine harvested using a modified commercial picker suitable for use in 0.76 m rows. Plants were sampled four times during the season to evaluate growth responses to PIX treatments.

RESULTS AND DISCUSSION: Seed cotton yield responses to applied mepiquat chloride treatments were not consistent across drip lateral depth treatments. Yields were significantly higher in the 21.9 L ha^{-1} and 36.6 L ha^{-1} mepiquat chloride application rates than in the untreated control only in the 60 cm lateral installation depth treatment. A trend existed toward lower yields in the untreated control in the other lateral depth treatments (Figure 1).

Plant growth, node number, and height measurements did not indicate significant differences due to mepiquat chloride treatments, but did indicate that plants were significantly smaller in the 60 cm deep drip lateral treatments when compared with the 30 and 45 cm deep lateral placement. Smaller plants in the 60 cm lateral depth treatments was thought to be a response to deeper water and fertilizer placement and the resulting delay in plant access to applied water and nutrients during early cotton growth stages. A detailed analysis of nutrient levels in petioles collected through the season indicated a potential interaction which influenced the interpretation of these results. Petiole NO_3-N and K levels were significantly lower in 60 cm drip lateral plots than in 30 and 45 cm treatments during the months of June and July, suggesting that root growth was not sufficient to obtain similar access to applied nutrients. In addition, the 36.6 L ha^{-1} mepiquat chloride treatments in all three drip lateral depth treatments consistently had higher petiole NO_3-N and K levels than the 21.9 L ha^{-1} treatment or untreated control. This was not thought to be an interaction with the mepiquat chloride treatment, but rather, a carry-over response from a 1991 experiment in which the plots in the 36.6 L ha^{-1} treatment

were used for a high nutrient application treatment which left high residual soil N and K.

FUTURE PLANS: Experiments conducted over the past four years have demonstrated that cotton will respond favorably (in terms of vegetation management and higher yields) to mepiquat chloride injected through the drip system. In previous studies we have conducted, improved vegetation management and yields were only achieved with high-dosage rate injections applied one or two times per season, whereas low-dose multiple injections were ineffective. Mepiquat chloride injections during the 1993 season were most likely not applied early enough in the season for maximum effectiveness, and any future studies with direct injection should focus on injections beginning prior to first flowering. The high dosage rate identified in this study would not be cost effective with the relatively small affects on yield that were achieved. Further field studies are not planned due to the high dosage rates required for significant responses. Additional greenhouse studies may continue as time permits to evaluate responses to applications made earlier in the growing season.

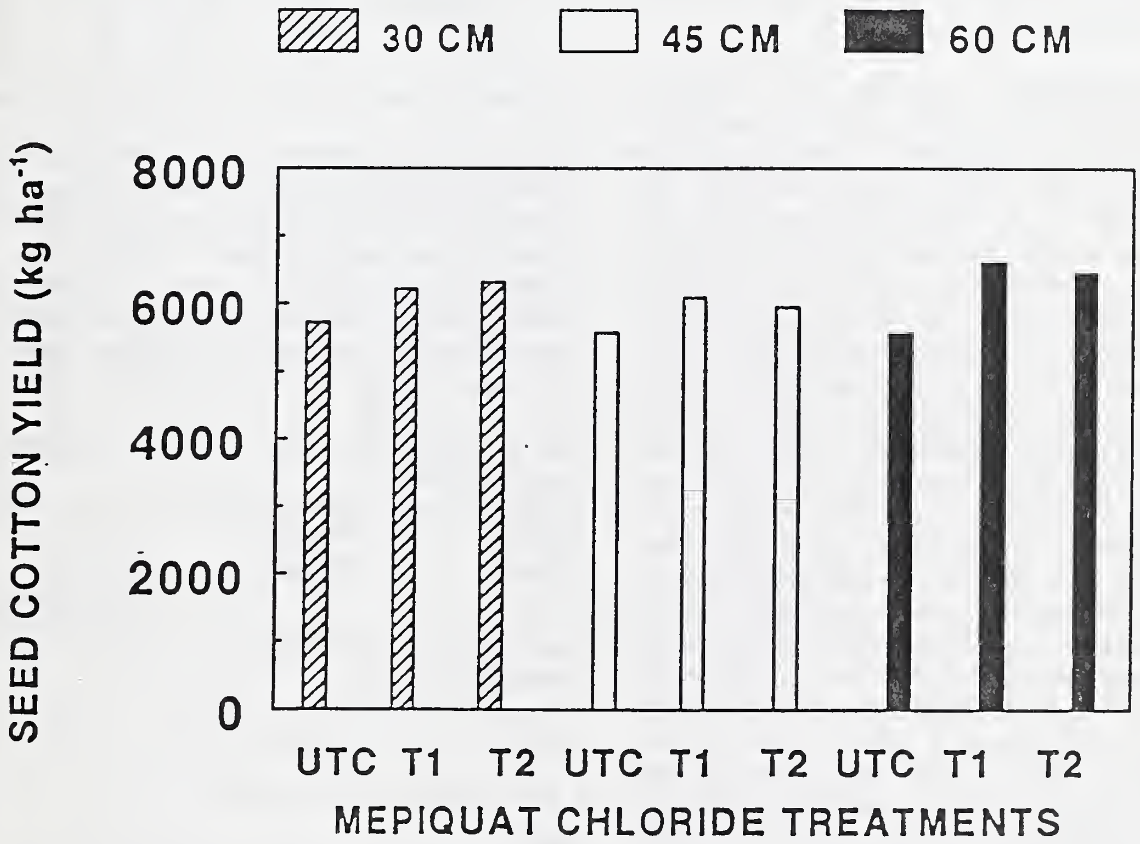


Figure 1. Average seed cotton yield responses to subsurface drip lateral depth (30, 45, 60 cm) and mepiquat chloride treatments (untreated control = UTC; 21.9 L ha^{-1} = T1; 36.6 L ha^{-1} = T2) in cotton grown at the West Side Research and Extension Center near Five Points, CA in 1993.

SUBSURFACE DRIP IRRIGATION OF ACALA AND PIMA COTTON: OPERATIONAL PROCEDURES

K.R. Davis, R.B. Hutmacher, C.J. Phene, R. Mead, S. Vail, C. Hawk
M. Peters, D. Ballard, N. Hudson, D. Clark, T. Kerby, and M. Keeley

OBJECTIVES: The overall objectives of this project are to evaluate the responses of three types of cotton grown using subsurface drip irrigation and a narrow-row (76 cm row spacing) production system. Crop water requirements, use of stored soil water, root distribution and density, and specific crop growth, plant water status, and gas exchange responses to irrigation ranging from mild to moderate deficit irrigation in a clay loam soil will be determined in this study.

PROCEDURES: Cotton was grown during 1993 in Panoche clay loam field plots (Fld 40, 54 plots) at the University of California West Side Research and Extension Center at Five Points, CA. Row spacing was 76 cm and the drip irrigation laterals, installed in 1991, were shanked about 45 cm deep in alternate furrows. The dripline installed was Rootguard in-line emitters with a nominal flow rate of 4 l/hr and a spacing of 0.9 m. Six subsurface drip irrigation (SDI) treatments (Table 1) were imposed on three cotton varieties (GC-510, Pima, and Columnar). In addition, each plot was split by PIX versus no-PIX treatments. The treatments were arranged in a randomized split-split plot design and were replicated three times. Each plot was about 27 m long and contained 10 beds. On March 8 and 9, 328 liters Vapam/ha was applied with about 18 mm water. Rainfall from December 1992 to April 1993 was 313 mm. No additional preplant irrigation was applied. Cotton was planted April 19 and about 25 mm of sprinkler irrigation for germination and emergence was applied April 21. The cotton was hand-thinned on May 27 to a final population of approximately 110,000 plants/ha. Subsurface drip irrigation (SDI) began on May 19, and for several days all treatments received approximately the same amount of water. Reference evapotranspiration (ETr) from a large weighing grass lysimeter located in an adjacent field and a crop coefficient (Kc) determined in 1980 and 1981 from this exact site were used for irrigation scheduling. The calculated ET_c(ETr x Kc) was multiplied by appropriate percentages (Table 1) to determine irrigation amounts. Fertilizer was injected at the headworks with flow-sensing proportioning pumps and applied with the irrigation water through the SDI system.

Table 1. Subsurface drip irrigation treatments as percentage of ETc for cotton (GC-510, Pima, and Columnar) during 1993.

Irrigation Treatment		ETc Percentage by Dates			
Number	Name	05/19 to 06/29	06/30 to 07/12	07/13 to 07/29	07/30 to 09/07
1	NS	100	100	100	100
2	NS/D80	100	100	100	80
3	NS/D60	100	100	100	60
4	NS/D80/D60	100	100	80	60
5	D80	100	80	80	80
6	D60	100	60	60	60

Table 2. Amount of fertilizer N, P, and K applied to all treatments in 1993.

Fertilizer Type	Pump No. ( ) and Dates	N	P	K
		kg/ha		
N(as Calcium Ammonium–Nitrate)	(1)06/07–07/28	183	–	–
P(as H_3PO_4)	(2)06/07–09/07	–	74	–
K and N(as KNO_3)	(1)07/29–09/07	26	–	77
Total		209	74	77

Fertilizer application is shown in Table 2. Soil water content was measured from May 14 to October 7 by neutron probe in access tubes installed in selected plots. The plant growth regulator, PIX, was applied on July 8. Irrigation was terminated on September 7. Cotton was defoliated on September 26, October 10, and October 17. Cotton was harvested with a single-row spindle picker from one row in each subplot on November 8, 1993.

RESULTS: Total water applied is shown in Table 3. By scheduling irrigation water as described, the in-season SDI water applied (averaged across varieties) was 507, 466, 426, 410, 443, and 378 mm for treatments 1-6, respectively.

FUTURE PLANS: The experiment will be changed to nitrogen management of cotton under subsurface drip irrigation for 1994.

Table. 3. Average water application for three cotton varieties (GC-510, Pima, and Columnar) in 1993.

	Water Applied				
Trt. #	Vapam	Sprinkler	Rain	SDI	Total
	mm				
1	18	25	313	507	863
2	18	25	313	466	822
3	18	25	313	426	782
4	18	25	313	410	766
5	18	25	313	443	799
6	18	25	313	378	734

SUBSURFACE DRIP IRRIGATION OF ACALA AND PIMA COTTON: I. PETIOLE NUTRIENT STATUS, GROWTH AND LINT YIELDS

R.B. Hutmacher, C.J. Phene, K.R. Davis, T. Kerby, M. Peters, S.S. Vail, R. Mead, D. Ballard, N, Hudson, A. Bravo, T. Pflaum, D. Clark, M. Keeley

OBJECTIVES: The objective of this project was to evaluate the growth and yield responses of three types of cotton grown under subsurface drip irrigation and a narrow-row (0.76 m row spacing) production system. Crop water requirements, use of stored soil water, root distribution and density, and specific crop growth, plant water status and gas exchange responses to irrigation ranging from mild to moderate deficit irrigation in a clay loam soil will be determined in this study for SDI and narrow row conditions.

PROCEDURES: Cotton was grown during 1993 in a Panoche clay loam soil at the University of California West Side Research and Extension Center. Row spacing was 0.76 m and the drip irrigation laterals were shanked in about 45 cm deep in alternate furrows, centered in the furrows. Details of the drip irrigation system, its operation and application amounts and methods of determining grass reference evapotranspiration (ETc). are given in this volume in the report "Subsurface drip irrigation of Acala and Pima cotton: Operational Procedures". Six subsurface drip irrigation treatments were evaluated, with the treatments representing six different combinations of percentages of crop ET applied during specific portions of the growing season, as described in the "operational procedures" report on this project.

A minimum of twenty petioles were collected from each of three field replicate plots of each treatment. Samples were collected from the fourth or fifth most recent node prior to 0930 hours PDT at 7 to 10 day intervals throughout the season, dried at 50 to 55 C, and analyzed for NO_3-N, PO_4-P, and K.

Cotton growth was evaluated using a number of non-destructive and destructive measures. Plant height, node number, and nodes above white flower were evaluated weekly on a minimum of six plants per field replication in all three blocks. Total leaf area, and dry and fresh weights of component plant parts (stem, leaf, and bolls) were determined using area harvests five times during the growing season. Cotton lint yields were measured on 25 to 30 m sections of planted rows in each plot using a modified commercial spindle-picker harvester. Cotton gin turnout percentages were determined at the University of CA/USDA Cotton Laboratory in Shafter, California.

RESULTS: Growth Measurements. Plant heights, total leaf area, and dry weights of component vegetative plant parts (stems, leaves) were significantly reduced in treatments receiving more severe deficit irrigation (treatments T3, T5 and T6). The amount which these parameters were reduced by varied from 6% to over 18%, with the largest reductions occurring in total plant leaf area and plant height in treatments T3 and T6 (60% ETc treatments during part of the irrigation season) (data not shown). General responses were in agreement with findings from the previous two years of this study.

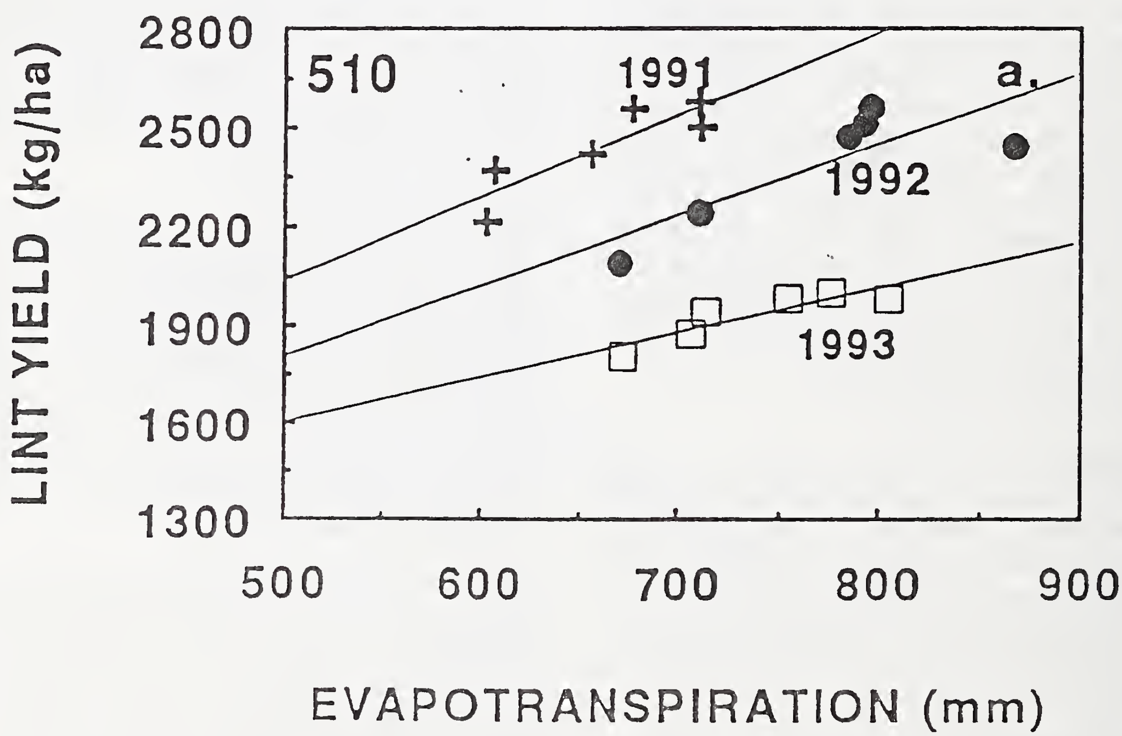
Petiole Nutrient Status. Nutrient applications across all irrigation treatments were uniform despite the differences in water applications. On most dates there were no significant interactions between irrigation treatments and petiole nutrient status (data not shown). The few significant differences that were observed were not significant for any extended time during the 1993 growing season.

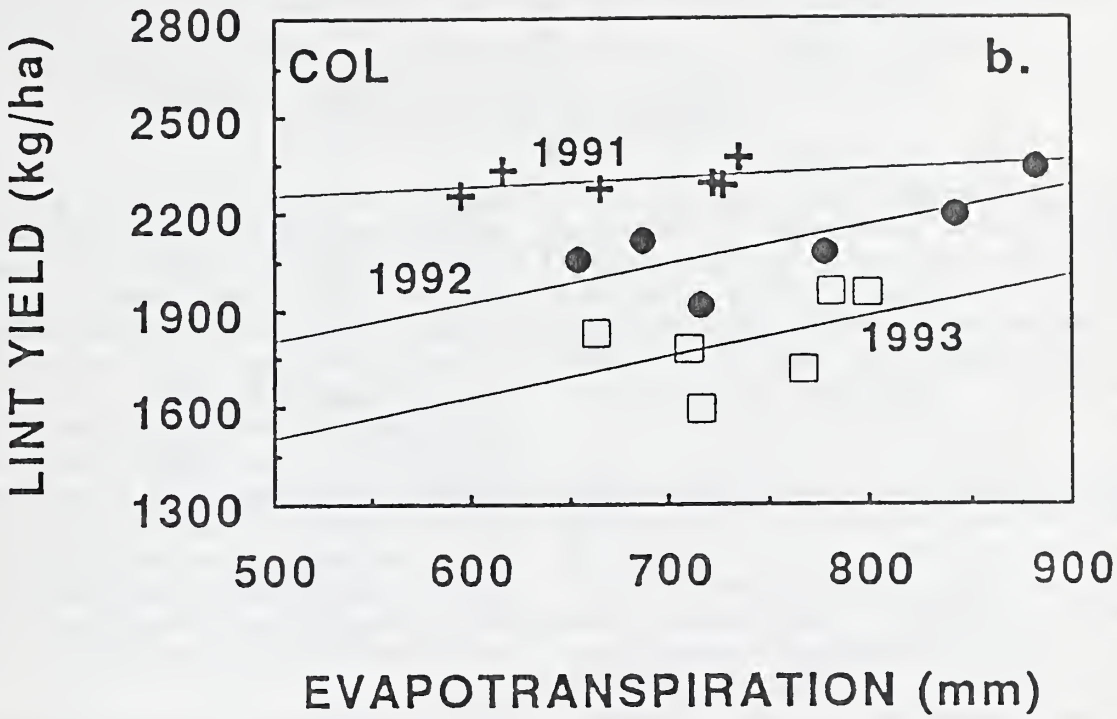
Petiole PO_4-P and K levels were generally slightly below or within University of CA "sufficient" levels (data not shown). Although no significant differences in petiole PO_4-P or K were observed between irrigation treatments, petiole K levels were significantly lower (about 8 to 15%) in Pima than in either Acala type, which agrees with the 1991 data in this study.

Across both Acala types of cotton and the Pima, petiole NO_3-N levels were generally slightly above or within about 6% of the University of CA recommended NO_3-N levels for cotton during the period from early through mid-season (prior to day 202) in all treatments (data not shown), as in previous years. After day 202, petiole NO_3-N levels were significantly below University of CA recommendations for late-season cotton. As in the previous two years of this study, early- to mid-season petiole NO_3-N levels in the Pima type were 10 to 20% lower than in comparable irrigation treatments in either Acala type (data not shown). Petiole nutrient levels were similar to those observed in previous years, and since lint yields were about 15% lower than in previous years, petiole nutrient status does not give any indications of a reason for lower yields. Soil nutrient data analyzed to date indicates that soil N levels were quite low at the beginning and end of the 1993 season, suggesting little carryover of N from previous crops.

Lint Yield. In 1993, lint yields were uniformly lower in all irrigation treatments than in 1991 and 1992 (Fig. 1). As in 1991, yield responses to PIX treatments were not consistent. Plant height and leaf area averaged smaller than in 1992 but were generally larger than in 1991 (data not shown). Despite ETc levels ranging from 660 to over 840 mm, lint yields generally did not increase significantly with increases in applied water or ETc in the Acala types. Significant yield increases only occured at the highest water application level (Treatment T1) in the Pima variety (Fig. 1).

FUTURE PLANS: The experiment was concluded with the 1993 season. A paper will be presented at the 1995 Beltwide Cotton Production Research Conference and others are planned.





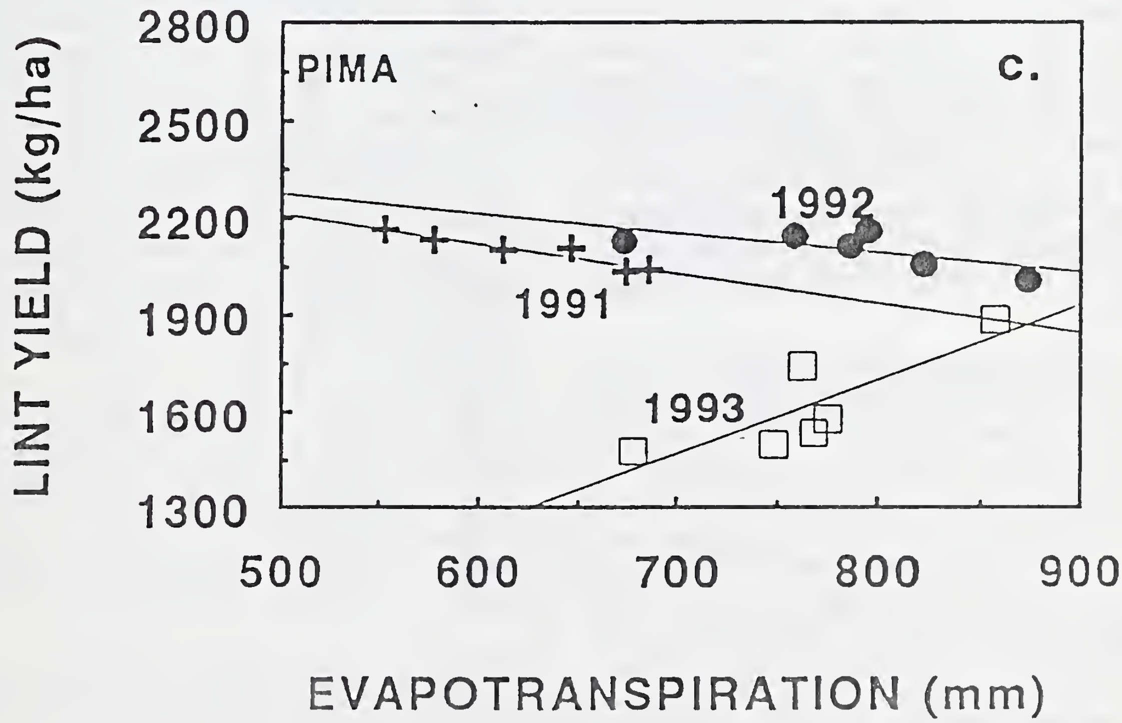


Figure 1. Lint yield of cotton irrigation treatments as a function of evapotranspiration (soil water depletion plus rain plus applied water) in 1991, 1992, and 1993 for (a) Acala variety GC510 ("510"); (b) experimental Acala Columnar ("Col") variety; and (c) Pima variety S6. Lines shown through data for each year are the best-fit linear regression.

SUBSURFACE DRIP IRRIGATION OF ACALA AND PIMA COTTON: II. PLANT WATER RELATIONS, LEAF CONDUCTANCE AND PHOTOSYNTHESIS

R.B. Hutmacher, C.J. Phene, K.R. Davis, T. Kerby, M. Peters, S.S. Vail, R. Mead, D. Ballard, N, Hudson, A. Bravo, T. Pflaum, D. Clark, M. Keeley

OBJECTIVES: Plant water status and the gas exchange responses of leaves of varying ages and positions on plants were evaluated at irrigation rates producing mild to moderate water deficits in a clay loam soil using SDI and narrow row production. This year (1993) was the third and final year in this study.

PROCEDURES: This three-year cotton study was conducted in a clay loam soil (Panoche clay loam) at the University of California West Side Research and Extension Center. Row spacing was 0.76 m and the drip irrigation laterals were placed about 45 cm deep in alternate furrows, centered in the furrows. Resulting drip lateral spacing was 1.52 m. Details of the drip system, applied water and specifics of irrigation treatments are given in this volume "Subsurface drip irrigation of Acala and Pima cotton: Operational Procedures". Six subsurface drip irrigation treatments were evaluated, with the treatments representing six different combinations of percentages of crop ETc applied during specific portions (pre-flowering, flowering, boll-filling) of the growing season, as described in the "Operational Procedures" report on this project.

The responses of three types of cotton were evaluated within each of the six irrigation treatments: (1) a commercial narrow-row adapted cotton (GC-510); (2) a columnar-type cotton produced out of the University of CA cotton program; and (3) a Pima type (Pima "S6"). All three types of cotton were grown at the same density and cultural conditions were identical across the three cotton types. Each individual plot was split into 5 rows which were sprayed once per season with the growth regulator "PIX" (Mepiquat chloride), and 5 rows which were not sprayed ("No PIX" plots), with the PIX applied in early July at a rate of 0.5 pints per acre.

Early- to mid-afternoon leaf water potentials (LWP) were determined on selected treatments (irrigation and growth regulator PIX treatments) in all three cotton types using a Schollander-type pressure chamber. Three subsamples were evaluated in each of three field replications for each treatment. Fully-illuminated recently-mature leaves from the fifth most recent main stem node were placed in a plastic bag while still on the plant, excised, and stored temporarily in humid, sealed plastic containers. Leaf water potentials were determined within 10 to 15 minutes following collection.

Gas exchange responses were evaluated only at two irrigation treatments, T1 and T6. These treatments represent those with the most (T1) and least (T6) applied water. Single leaf photosynthetic rates were determined using a flow-through chamber system with an ADC gas analyzer. A 4.2 cm^2 area was monitored on each sample leaf. Although data was collected to a limited extent on all three cotton types, the emphasis was on GC510, and only that data will be discussed here. Measurements were made on leaves located on the 3rd, 5th, 8th and 11th most-recent main stem nodes, and on the 1st and 2nd position (if present) sympodial leaves arising from the 8th through 11th most-recent nodes. In the upper canopy positions, leaves were fully-illuminated, while lower canopy leaves were monitored under ambient light levels. Data was recorded by node position and average leaf initiation date in order to accurately identify leaf age as well as position.

RESULTS: Leaf Water Potential- Plant Water Relations. As in the two previous seasons, few significant differences in LWP existed between the Columnar and GC510 types within any irrigation treatment (data not shown). In the early season (prior to about day 190), LWP in the higher water application treatments in the Acala types averaged about -1.3 to -1.5 MPa, declining

to about -1.4 to -1.6 MPa through day 215 (Fig. 1, 2). Even in the higher water application treatment (T1), LWP declined to about -1.6 to -1.8 MPa in the boll-filling period prior to irrigation cutoff. In contrast, the treatment receiving the least applied water (T6) in the Acala types averaged a LWP of -1.8 to -2.0 MPa prior to day 215 and declined to about -2.1 to -2.4 MPa in the boll-filling period (Fig. 1, 3). LWP values were generally similar to those determined during the same period in the 1992 season, but were 0.10 to 0.25 MPa lower than during comparable periods in the 1991 season, reflecting lower initial stored soil water levels than in 1991.

Across all irrigation treatments, (T1 in Fig. 2, T6 in Fig. 3), the Pima type cotton exhibited 0.1 to 0.2 MPa lower LWP than the Acala types. These findings are in agreement with results from the two prior seasons of this experiment. A less extensive root system or differences in plant hydraulic resistance to water flow may be indicated by the consistent differences in LWP despite exposure to identical growing conditions and applied water.

Gas Exchange. As in 1991 and 1992, net photosynthetic rates of leaves were not always tightly linked with leaf conductance. Leaf photosynthetic rates were consistently highest in leaves at the 5th most recent node. When averaged across all sampling dates, photosynthetic rates averaged 16%, 6%, and 32% lower in fully-illuminated 3rd, 8th, and 11th most-recent main stem leaves, respectively (data not shown). Leaf conductances were highest in 3rd and 5th position leaves.

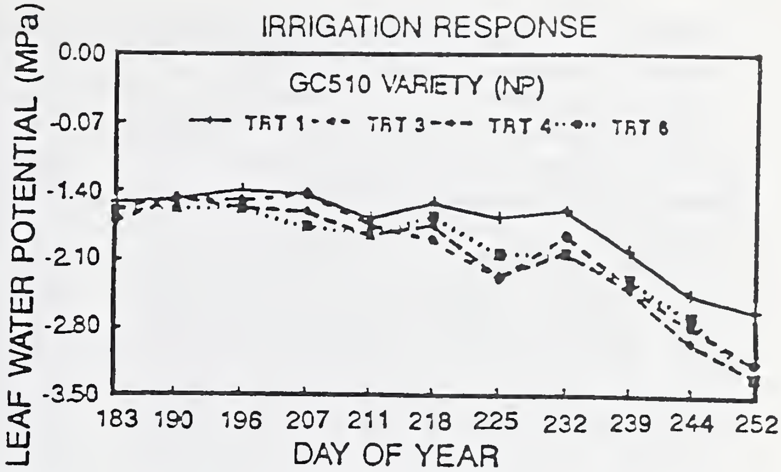


Figure 1. Leaf water potential (LWP) as a function of irrigation treatment (for treatments T1, T3, T4 and T6 only) and day of year in GC510 variety (with no PIX application "NP") in 1993.

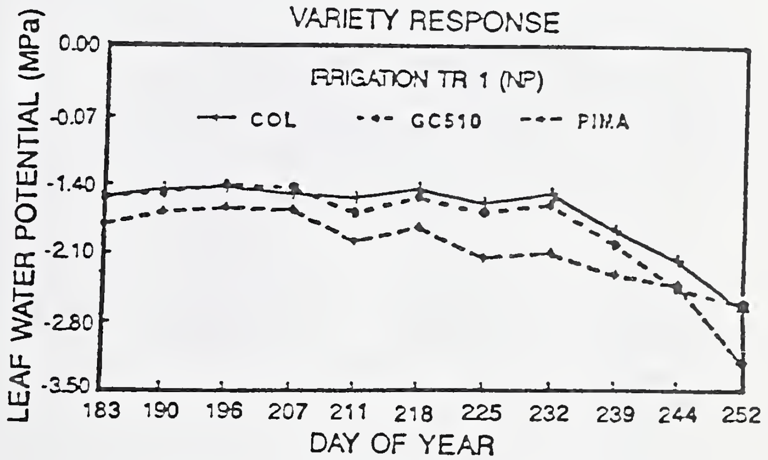


Figure 2. Leaf water potential (LWP) as a function of variety and day of year for Acala GC510, Columnar ("COL"), and Pima types in the high water application treatment (T1) in 1993.

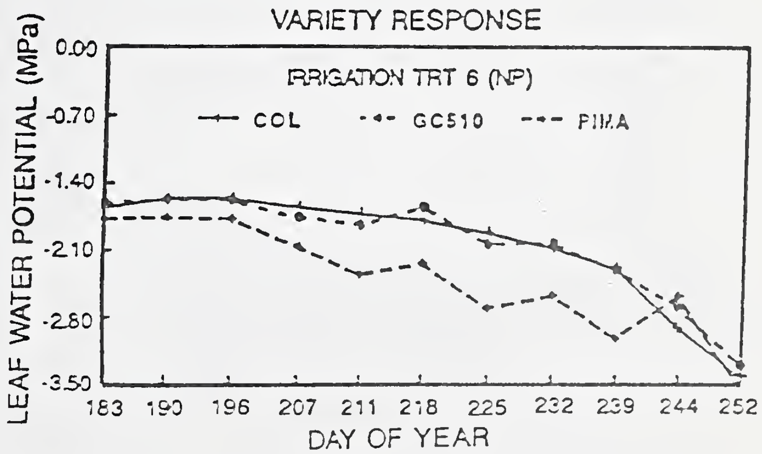


Figure 3. Leaf water potential (LWP) as a function of variety and day of year for Acala GC510, Columnar ("COL"), and Pima types in the low water application treatment (T6) in 1993.

During the boll-filling period (mid-July through August), lower canopy leaves (11th most recent main stem leaf and symodial leaves) were routinely under low photosynthetic photon flux density (PPFD) levels (less than 400 μmol photons $m^{-2} s^{-1}$), resulting in net photosynthetic rates ranging from near 0 to about 30% (5 to 6 μmol CO_2 $m^{-2} s^{-1}$) of rates in upper canopy main stem leaves. Low photosynthetic rates in these low illumination-acclimated leaves were not just a function of declining photosynthetic capacity as leaves aged, but rather, reductions in photosynthetic rates and leaf conductance were linked with low PPFD. Leaves in comparable positions which were at PPFD levels greater than 800 μmoles photons $m^{-2} s^{-1}$ maintained photosynthetic rates greater than 60% to 70% of those in the upper canopy, even during boll-filling.

FUTURE PLANS: The 1993 season concludes this experiment. A paper will be presented at the 1995 Beltwide Cotton Research Conference covering some aspects of this study and other manuscripts and presentations will be prepared.

FOLIAR METHANOL APPLICATIONS: EFFECTS ON COTTON GAS EXCHANGE, GROWTH, YIELD IN FIELD STUDY

R.B. Hutmacher, A.D. Bravo

OBJECTIVE: Recent information from an Arizona farmer and a California researcher implicated foliar methanol applications in improvements in cotton and vegetable crop yields under desert conditions. These findings received a great deal of attention at industry meetings and the popular press. In response to a nationwide effort to involve cotton researchers in investigating the potential influence of methanol on crop water use and yield, we participated in an investigation of the influence of a range of concentrations of methanol applied at specific growth stages on cotton leaf conductance, photosynthetic rates, overall plant growth and boll production.

PROCEDURES: The field test was conducted in 1993 in small subplots of a larger experiment on subsurface drip irrigated, narrow-row (0.76 m spacing) cotton (Gossypium hirsutum var. "Maxxa") grown at the University of California West Side Research and Extension Center near Five Points, CA. About 60 mm of water was applied at planting to germinate and establish the crop. The cotton received about 490 mm of irrigation during the growing season and used an average of over 240 mm of stored soil water in the upper 2 m of the soil profile. Rainfall totalled 117 mm during the growing season. The crop was generally not subject to any significant water deficits, with crop water stress index values (CWSI) not exceeding 0.2 until mid-August. N, P, and K fertilizer were supplied through the drip system (210 kg N/ha, 76 kg P/ha, 145 kg K/ha) and all petiole nutrient levels were close to or above recommended values during all growth stages.

Plot areas used in the foliar methanol applications were four rows wide (2 beds) by 18.3 m in length. No irrigation or fertilizer variables were tested, only different rates and timing of methanol applications. The hypothesis tested was whether a minimum number of foliar methanol applications could influence total plant growth and cotton yield. Four treatments (water spray, 24% methanol, 30% methanol, and no spray) were applied on 3 field replicates, with four separate spray date subtreatments (application of all three different rates on 6/24, 7/08, 7/22, or all three dates). Spray volume applied per treatment date was at a rate of 200 L/ha, or approximately 1.2 L per plot.

RESULTS AND DISCUSSION: Yields were generally high in all plots (ranging from 5673 kg seed cotton per ha to a high of 6732 kg/ha, Table 1). Yield was significantly higher in only one treatment receiving methanol applications (24% methanol applied on all dates), with

Table 1. Seed cotton yield responses to foliar-applied methanol treatments at the West Side Research and Extension Center near Five Points, CA in 1993. Treatment differences shown are only significantly different from the "No Spray" control.

Methanol treatment (concentration of spray solution, %)	Spray date treatment (see code below)[z]	Seed cotton yield (kg/ha)
24	1	6083
	2	6117
	3	5878
	4	6732* [y]
30	1	5673*
	2	6083
	3	5912
	4	5946
0–water spray	1	6145
	2	5696*
	3	6258
	4	6162
No Spray	–	6345

[z]spray date treatments code as follows: (1 = one spray on 6/24; 2 = one spray on 7/08; 3 = one spray on 7/22; 4 = sprayed all dates)

[y]signifies significantly different from the "no spray" control treatment.

6732 kg seed cotton/ha versus 6345 kg/ha in the "No Spray" treatment and an average of 6070 kg/ha in the "water spray" treatments. Two other spray treatments, however, had significantly lower yields than the rest (30% methanol applied on 6/24; water spray alone on 7/08).

When compared with the untreated control or other treatments, final plant height and leaf area averaged 6% and 5% higher, respectively, in 24% and 30% methanol treatments applied on 6/24 or on all three dates (apparent differences, however, were not significant). Plant water status (CWSI, leaf water potential) was unaffected by methanol treatments on late-June, mid-July, and early-August measurement dates. Leaf conductance of upper canopy leaves in 24% and 30% methanol treatments was highly variable but averaged 2% to 6% higher (not significant) than control plants during the same three measurement periods, but only for a few days following spray applications.

FUTURE PLANS: Our findings were reported in cooperation with researchers from the Texas Agricultural Experiment Station at the Agronomy meetings in 1993 and Cotton Production Conference in 1994, and a joint paper is being considered.

Field studies did not consistently indicate significant cotton responses to methanol treatments. Additional container-grown cotton studies will be attempted, but only one field experiment is planned for the coming season. Methanol (24%) versus water (control) spray will be applied to field-grown plants at times corresponding with expansion of the leaves at nodes 3, 5, 7, 9, and 11 to evaluate potential responses during vegetative growth stages.

FOLIAR METHANOL APPLICATIONS: EFFECTS ON COTTON GAS EXCHANGE, GROWTH, YIELD IN CONTAINER-GROWN PLANTS

R.B. Hutmacher, A.D. Bravo

OBJECTIVE: Recent information from an Arizona farmer and a California researcher implicated foliar methanol applications in improvements in cotton and vegetable crop yields under desert conditions. These findings received a great deal of attention at industry meetings and the popular press. In response to a nationwide effort to involve cotton researchers in investigating the potential influence of methanol on crop water use and yield, we participated in an investigation of the influence of a range of methanol concentrations applied at specific growth stages on cotton leaf conductance, photosynthetic rates, overall plant growth and boll production.

PROCEDURES: The container-grown plant studies were in 7 liter containers with 3 to 5 replications per treatment. Several individual studies were conducted; (EXPERIMENT 1) an evaluation of effects of spray concentrations (water vs. 12%, 18%, 24%, 30%, 36% methanol) on total plant height and dry matter, and gas exchange, with spray treatments applied weekly for 6 weeks beginning at pinhead square; (EXPERIMENT 2) effects of timing of application (2 sprays at 24% methanol/week for a three week period beginning at pinhead square or 1, 2, or 3 weeks after pinhead square); (EXPERIMENT 3) effects of number of spray methanol applications (combination of 1 or 2 applications of 24% methanol solution per week for duration of 1, 2, or 4 weeks); and (EXPERIMENT 4) effects of methanol spray applications to single leaves versus whole plant treatments. All plants were received water from one drip emitter per container and received liquid fertilizer applied with the water. Water applications were adequate to prevent any significant soil water deficits.

RESULTS AND DISCUSSION: Summarized as follows for individual experiments:

Experiment 1 (Methanol concentration responses): Methanol treatments of 24% and 30% had the greatest impact on plant gas exchange and total dry matter production (Table 1). Plants were significantly taller in 18, 24, and 30% methanol treatments, but dry matter partitioning was unaffected.

Table 1. Methanol spray concentration effects on dry matter and gas exchange components in container-grown cotton, 1993.

Methanol spray concen-tration (%) spray	Final total dry matter (% of 0% methanol treatment)	Average leaf conductance (% of 0% trt.)		Average net photosynthesis (% of 0% trt.)	
		During spray period	4 weeks after last spray	During spray period	4 weeks after last
water spray	100	100	100	100	100
12	96	106	94	92	98
18	104	109	95	106	96
24	112	106	94	110	102
30	108	114	101	108	97
36	94	111	98	96	91

Experiment 2 (spray timing effects): Plants sprayed beginning at pinhead square and one week after pinhead square averaged 9% and 5% larger total dry matter, respectively, than the average total dry matter for other treatments. Plants in which spray treatments began earlier tended to be taller than in those spray treatments initiated later in the season.

Experiment 3 (number of spray applications): Final plant total dry matter and plant height did not respond consistently to the number of spray applications, although some tendency existed for larger plants (about 4 to 6% larger, not significant) in treatments receiving methanol applications for a longer period, ie. weekly applications for 2 to 4 weeks). In general, the influence of methanol applications on single leaf photosynthesis and leaf conductance is

greatest within 6 days after application and did not persist beyond 8 to 10 days.

Experiment 4 (responses to single leaf versus whole plant methanol applications): When only single leaves were sprayed, leaf conductance and net photosynthetic rates were only affected in sprayed leaves, not in other leaves on the same plants. Total dry matter and plant height were only affected when 24% methanol was sprayed on the entire plant.

<u>FUTURE PLANS</u>: Our findings were reported in cooperation with researchers from the Texas Agricultural Experiment Station at the Agronomy meetings in 1993 and Cotton Production Conference in 1994, and a joint paper is being considered.

WATER REQUIREMENTS OF SUBSURFACE DRIP IRRIGATED SUDANGRASS IN THE IMPERIAL VALLEY: OPERATIONAL PROCEDURES

R.M. Mead, R.B. Hutmacher, C.J. Phene, D.A. Clark, R. Swain, T. Donovan, D. Kershaw, S.S. Vail, M.S. Peters, C.A. Hawk, P. Shouse, M. van Genuchten, J. Jobes

OBJECTIVES: The objectives of this experiment were to evaluate the ability of a subsurface drip irrigation system installed at 63 to 70 cm depth to supply water requirements of a sudangrass crop. Crop water use will be monitored and responses to four subsurface drip irrigation treatments will be compared with furrow-irrigated sudangrass. This crop was grown as an intermediate crop between the previous alfalfa crop (grown from 1990 through early 1993) and the alfalfa crop planted in 1994, and was planted within 2 months after installation of new drip line.

PROCEDURES: Replacement drip laterals were installed in the winter and spring of 1993 at a depth of 63 to 70 cm. Three replications of each of five irrigation treatments were investigated in this experiment. There are two drip lateral spacing treatments, 1.02 m and 2.04 m, with the drip laterals placed 60 to 67 cm below the center of each bed, on 1.02 m and 2.04 m beds, respectively. Two different types of drip tubing were used with each row spacing: (a) pressure-compensating in-line emitters on 20 mm tubing (RAM); and (b) turbulent-flow in-line emitters made out of herbicide-impregnated plastic (Rootguard). Both emitter types have a nominal flow of 2 L h^{-1} at 18 to 20 psi. Emitter spacing along the laterals is 40 inches (1.02 m) in both types of tubing. Phosphoric acid was continuously injected in the irrigation water in all drip plots to achieve a final concentration of 15 mg P L^{-1}. An initial broadcast application of a phosphorus-containing fertilizer supplied 55 kg P ha^{-1} in all plots, and side-dress applications of phosphorus were made in furrow-irrigated plots to equal season total P applications in drip plots.

RESULTS / DISCUSSION: *System Operation and Management*. During the months of sudangrass growth (March through September), in excess of 500 mm of water were applied using the subsurface drip irrigation system. Unlike the previous installation at 45 cm lateral depth, no surface soil wet areas were observed during operation of the drip system, even when in excess of 6 mm were applied in one continuous operation or when more than 12 mm of water were applied during any one day. Some of this lack of upward water movement can be attributed to the deep tillage and shanking operations associated with installation of new drip laterals. Water applications in excess of 200 cm were made prior to field preparation for the sudangrass in order to settle the soil and close the damage to soil structure done by the drip line shank. Preliminary observations during the sudangrass cycle in this project indicate that the deep lateral installation severely reduced or eliminated the surface soil wetting problem.

Water Applications and Forage Yields. Total water applications with furrow irrigation were 728 mm, while an average of 536 mm of water was applied using the drip system in the subsurface drip plots (Table 1). In addition, all plots received about 84 mm of sprinkler irrigation after seeding for germination and stand establishment. Sudangrass yields were significantly lower in the 2.04 m lateral spacing in the RAM

Table 1. Total water applications (sprinkler germination plus furrow or drip irrigation) and forage yields for both harvests of sudangrass (7/15/93 and 9/07/93) as a function of irrigation treatment in 1993 at USDA-ARS Irrigated Desert Research Station near Brawley, CA.

Irrigation treatment	Type of drip tubing	lateral spacing (mm)	(Mg/ha) corrected to same moisture % 7/15	9/07	Total	water applied (mm)
Subsurface	Rootguard	1.02	2.36	2.38	4.74	633
drip	"	2.04	2.30	2.95	5.25	608
Subsurface	RAM	1.02	2.22	2.35	4.57	625
drip	"	2.04	2.02	3.05	5.07	614
Furrow	–	–	2.65	2.36	5.01	812

tubing at the first harvest date (7/15/93), with no significant differences across other treatments on the first harvest date (Table 1). On the second harvest date (9/07/93), sudan-grass yields were significantly higher in the 2.04 m spacing with both types of tubing than in the other treatments. Total sudangrass yields across both harvests, however, were not significantly different across the treatments. The water use efficiency in terms of forage yield per unit of applied water was much higher (about 28% higher) under subsurface drip than under furrow irrigation.

FUTURE PLANS: Following removal of the last sudangrass crop, the field was prepared for re-planting the alfalfa crop. The field was cross-disked and re-bedded, and bed alignment with the drip system was checked and corrected where necessary.

POTASSIUM FERTILIZATION OF FRESH-MARKET TOMATOES UNDER SUBSURFACE DRIP IRRIGATION

R.B. Hutmacher, C.J. Phene, J. Liu, M. Zick,
M.S. Peters, C.A. Hawk, D.A. Clark

OBJECTIVES: Potassium fertilization is not often recommended for many agronomic and horticultural crops in the central San Joaquin Valley due to what is perceived as adequate soil potassium levels to meet plant needs. In recent years, however, crops such as cotton and some vegetable crops have responded favorably to potassium applications in San Joaquin Valley soils which usually test low to moderate in soil K. In previous studies we determined that processing tomatoes accumulate large quantities (in excess of 500 kg K ha^{-1}) under high yield conditions, and the majority of this amount is removed from the field in fruit at harvest. A field project was initiated to determine potential fresh-market tomato growth and yield responses to a range of potassium applications when potassium is applied continuously with the irrigation water under subsurface drip irrigation.

PROCEDURES: Fresh-market tomatoes (var. "Ace") will be grown in a Hanford sandy loam soil in the southeast Fresno area. Tomatoes will be grown on 1.52 m beds, with two planted rows, 0.3 m apart, on each bed. The drip system consists of a single drip lateral centered 45 cm below the average soil surface in each bed, with 5 beds per plot, each 13.5 m in length. The drip emitters have a nominal flow of 2 L h^{-1} at a working pressure of 18 to 20 psi, and are 45 cm apart along each lateral.

Five fertilizer treatments will be imposed as follows: (1) untreated control receiving no potassium fertilization; (2) 140 kg K ha^{-1} applied as KNO_3; (3) 280 kg K ha^{-1} applied as KNO_3; (4) 420 kg K ha^{-1} applied as KNO_3; and (5) 420 kg K ha^{-1} applied as KCl. Each fertilizer treatment also will receive nitrogen and phosphorus fertilizer. Phosphoric acid will be used to apply about 250 kg P ha^{-1} uniformly to all treatments as a continous injection of about 15 mg L^{-1}. Calcium ammonium nitrate will be used to supply all N fertilizer to potassium treatment #1 and #5, while it will be applied to supplement N supplied by KNO_3 in the other treatments. Total N applications for each week and for the whole season will be equal across all K treatments. A combination of venturi-type and proportional flow injectors will be used to inject fertilizer solutions. Water applications will be identical across treatments, will be measured using water meters, and will be keyed to meet local CIMIS weather station reference evapotranspiration multiplied by a tomato crop coefficient developed at the USDA-ARS-WMRL.

The tomatoes will be planted in March and harvested in July and August, with two to three harvests at about 10 day intervals. Fruit will be classified according to size and quality characteristics, with fruit average size in each class and total fruit number recorded. Petioles of upper canopy fully-illuminated and expanded leaves will be collected at 7 day intervals and NO_3-N, PO_4-P and K levels will be determined. Leaf blades from the same locations as petiole samples will also be collected to evaluate plant storage of nutrients. Plant water status will be monitored using crop water stress index (CWSI) and leaf water potential methods. Plant above-ground dry matter samples will be collected three to four times during the growing season to determine growth responses to K treatments and to provide dry matter weights and samples for determining nutrient uptake as a function of growth stage.

PROGRESS / FUTURE PLANS: The 1993 season is expected to be the first of several years in this study. Soil samples will be taken during each year of the study to determine initial soil nutrient status and depletion/accumulation of nutrients resulting from the fertilizer treatments. This project will serve as a Master of Science Thesis project for a student at California State University, Fresno. The thesis will be prepared based on the 1993 data. Summary reports will also be prepared and submitted to Vicksburg Chemical Co., a cooperator in this study.

WATER REQUIREMENTS OF SUBSURFACE DRIP IRRIGATED ONIONS IN THE IMPERIAL VALLEY: I. OPERATIONAL PROCEDURES

R.B. Hutmacher, R.M. Mead, C.J. Phene, D.A. Clark, R. Swain, T. Donovan, D. Kershaw, S.S. Vail, M.S. Peters, C.A. Hawk, P. Shouse, M. van Genuchten, J. Jobes

OBJECTIVES: The row crop subsurface drip irrigation (SDI) project at the Irrigated Desert Research Station of the USDA-ARS in Brawley, CA is a five-year evaluation of water requirements of select annual crops and the influence of irrigation management on soil accumulations of salts and potentially yield-limiting specific ions. The objectives of this experiment are to study and compare crop responses, irrigation water requirements, and salinity accumulations as affected by SDI systems. Initial plans were to include processing tomatoes, cantaloupe, cotton and lettuce in this study, but plans have been altered to lettuce, cotton, sweet onions and perhaps processing tomatoes and broccoli due to the continued threat of white fly damage associated with the severe infestation plaguing the Imperial Valley since 1991.

PROCEDURES: Drip tubing / Field Layout / Field Operation: Drip tubing with a wall thickness of 0.5 mm (Netafim, Inc., Typhoon type) was installed at a depth of 0.40 m below the average soil surface in the center of each planting bed. Field F-3 of the USDA-ARS Brawley Research Station was prepared with beds 1.52 m in width. Emitters on the drip laterals were spaced 1.02 m apart and are of a turbulent-flow design with a nominal output of 2 L h^{-1}. Each plot consists of six beds 80 m in length. There are four irrigation treatments with four replications in a randomized complete block design. Each irrigation treatment has electronic water meters and pressure transducers which can be continuously monitored using a data logger/computer control system accessible from the USDA-ARS-WMRL in Fresno or from other remote locations. A fertilizer injection system consisting of a mixing tank and proportional flow injectors was used for N, P and K injections through the SDI system. Sixteen access tubes were installed (one per plot) to allow soil water content measurements using neutron attenuation.

In November 1993 six rows of onion seeds (equally spaced) were planted per 1.52 m east-west oriented bed, with the variety "Henry's Special" planted in the 4 center plot harvest rows and "Colossal" planted in border rows. Pre-plant fertilizer (11-48-0) was applied at a rate of 168 kg ha^{-1} uniformly across all treatments. A total of 112 kg P ha^{-1} and 232 kg N ha^{-1} were applied (including both pre-plant and within-season applications made with the irrigations). N and P applications made with the SDI system were as calcium ammonium nitrate and phosphoric acid, respectively. During the period from planting through harvest, 98 mm of rain fell. Seed was germinated and the crop established using 106 mm of sprinkler irrigation.

Final onion yields were determined on day of year 128 on two 4 m sections of beds in each plot, with all six rows hand-harvested in groups of two rows (center two rows, northern two outer rows, southern two outer rows). Bulk onion fresh weights were determined in each separate group of rows, graded according to commercial size classifications, and the number and bulk weight of onions in each size recorded. Onions were sampled at several times during the growing season to assess nutrient status and relative effects of treatments on growth and development.

An additional split irrigation treatment was initiated about 3 weeks prior to harvest to determine if a late-season sprinkler application of 75 mm would improve onion size. The east half of the field received this sprinkler irrigation while the west half did not. Soil samples were collected at the beginning and end of the onion experiment to characterize the influence of variable irrigation rates

on accumulation of salts and chemical constituents in the soil profile.

Irrigation Control / Matric Potential Sensor System: Irrigation was controlled to meet some multiple of crop evapotranspiration (ETc) as determined using CIMIS reference evapotranspiration multiplied by a crop coefficient determined using long-term Imperial Valley water use data for onions. Treatments #1, 2, 3 and 4 were designed to receive approximately 60%, 80%, 100% and 120% of calculated crop evapotranspiration, respectively. but actually received 59%, 76%, 100% and 139% of estimated ETc. Twenty soil matric potential sensors in treatment #3 were used to monitor soil matric potential 45 cm below the soil surface and 10 to 15 cm laterally from each of five sensors per treatment block. See additional report in this volume for specifics on experimental methodology and results from use of the matric potential sensors.

RESULTS / DISCUSSION: Due to the relatively late planting date and the fact that onions are not considered a host for whitefly, there was little or no whitefly pressure on this crop. There were again (as in previous planting with lettuce) stand establishment problems and some areas with poorly-developed plants. Problems with seedbed preparation were the general cause of problems noted, with the soil quite cloddy due to restricted tillage operations so as to not disrupt bed orientation relative to the drip line. Additional work or equipment will be needed to improve seedbed preparation while still not disrupting existing drip line installations.

FUTURE PLANS: Following removal of the sweet onion crop, the field will remain fallow for the summer months and then be prepared for a winter crop of broccoli as the next rotation crop. Soil sampling will continue to be an important part of this sequence of studies, with samples collected before and after each crop to determine long-term influence of drip irrigation treatments on accumulations of salts and other constituents in the profile.

WATER REQUIREMENTS OF SUBSURFACE DRIP IRRIGATED ONIONS IN THE IMPERIAL VALLEY: II. YIELD RESPONSES

R.B. Hutmacher, R.M. Mead, C.J. Phene, D.A. Clark, R. Swain, T. Donovan, D. Kershaw, S.S. Vail, M.S. Peters, C.A. Hawk, P. Shouse, M. van Genuchten, J. Jobes

OBJECTIVES: The row crop subsurface drip irrigation (SDI) project at the Irrigated Desert Research Station of the USDA-ARS in Brawley, CA is a five-year evaluation of water requirements of select annual crops and influence of irrigation management on soil accumulations of salts and potentially yield-limiting specific ions. The objectives of this experiment are to study and compare crop responses, irrigation water requirements, and salinity accumulations as affected by SDI systems. Initial plans were to include processing tomatoes, cantaloupe, cotton and lettuce in this study, but plans have been altered to lettuce, cotton, sweet onions and perhaps processing tomatoes and broccoli due to the continued threat of white fly damage associated with the severe infestation plaguing the Imperial Valley since 1991.

PROCEDURES: For a general description of the plot layout and basic operational procedures, see "Water Requirements of Subsurface Drip Irrigated Onions in the Imperial Valley: Operational Procedures" in this volume. There are four irrigation treatments with four replications in a randomized complete block design.

Six rows of onion seeds (equally spaced) were planted per 1.52 m east-west oriented bed, with the variety "Henry's Special" planted in the 4 center plot harvest rows and "Colossal" planted in border rows. During the period from planting through harvest, 98 mm of rain fell. Seed was germinated and the crop established using 106 mm of sprinkler irrigation. Final onion yields were determined on two 4 m sections of beds in each plot, with all six rows hand-harvested in groups of two rows (center two rows, northern two outer rows, southern two outer rows). Bulk onion fresh weights were determined in each separate group of rows, graded according to commercial size classifications, and the number and bulk weight of onions in each size recorded. Onions were sampled at several times during the growing season to assess nutrient status and relative effects of treatments on growth and development. An additional split irrigation treatment was initiated about 3 weeks prior to harvest to determine if a late-season sprinkler application of 75 mm would improve onion size. The east half of the field received this sprinkler irrigation while the west half did not.

Irrigation Control / Matric Potential Sensor System: Irrigation was controlled to meet some multiple of crop evapotranspiration (ETc) as determined using CIMIS reference evapotranspiration multiplied by a crop coefficient determined using long-term Imperial Valley water use data for onions. Treatments # 1, 2, 3 and 4 were designed to receive approximately 60%, 80%, 100% and 120% of calculated crop evapotranspiration, respectively. but actually received 59%, 76%, 100% and 139% of estimated ETc. Twenty soil matric potential sensors in treatment #3 were used to monitor soil matric potential 45 cm below the soil surface and 10 to 15 cm laterally from each of five sensors per treatment block. See additional report in this volume for specifics on experimental methodology and results from use of the matric potential sensors.

RESULTS / DISCUSSION: Yield and Yield Components: Onion yields were significantly lower in the low water application treatment (#T1) than in the other treatments (Table 1).

Table 1. Yields of onions (harvested May 8, 1994) and total season applied irrigation water as a function of irrigation treatments in plots at the USDA-ARS Irrigated Desert Research Station near Brawley, CA in 1994.

Irrigation	Onion yields (Mg/ha)		Applied water (mm) [z]	
treatment number	Plots not sprinkled	Plots sprinkled	Plots not sprinkled	Plots sprinkled[y]
T1	34.1 b [x]	32.4 b	318	393
T2	43.2 a	43.6 a	379	454
T3	41.7 a	38.7 ab	463	538
T4	42.9 a	41.6 a	601	676

[z] includes 106 mm water applied by sprinklers to germinate and establish crop.
[y] sprinkler application of 75 mm applied to one half of each plot in each treatment 3 weeks prior to harvest.
[x] yields are significantly different at the 5% level of significance if followed by a different letter.

Increases in water application beyond the amounts in treatment #T2 (379 to 454 mm) did not increase yields (Table 1). The addition of late-season irrigations using sprinklers also did not significantly increase yields.

At the irrigation frequency threshold of 2 mm, lateral water distribution from the emitters wetted the soil within 10 to 15 cm of the soil surface under the center of the planted beds, but at the outer planted rows on either the north or south edge of each bed, soil was consistently wetted no closer than 20 to 25 cm of the soil surface. This resulted in a higher incidence of moderate to severe water deficits and smaller onions and yields in the planted rows most distant from the emitters in the relatively shallow-rooted onions (Table 2). Between 41 and 48 percent of total onion yields (weight) in each bed were from the center two rows of each bed. Late-season supplemental sprinkler irrigations did not consistently influence the relative yield.

Table 2. Distribution of onion yield according to locations within the bed, primary drip irrigation treatments, and supplemental sprinkling treatments. Experiment was conducted at the USDA-ARS Irrigated Desert Research Station near Brawley, CA.

		% of total yield/1.52 m wide bed		
Irrigation treatment number	Supplemental sprinkling treatments	North two rows in bed	Center two rows in bed	South two rows in bed
T1	Not sprinkled	32	44	24
	Sprinkled	36	42	22
T2	Not sprinkled	25	48	27
	Sprinkled	22	48	30
T3	Not sprinkled	35	43	22
	Sprinkled	35	41	24
T4	Not sprinkled	31	48	21
	Sprinkled	30	47	23

There was a trend toward a greater percentage of larger onions in the higher water treatments, but the effect was not always significant (Table 3). Supplemental sprinkler irrigations also did not significantly influence size distribution. The variability in onion size across the

Table 3. Distribution of onion yields by onion size classifications as influenced by primary drip irrigation treatments and supplemental sprinkler irrigation treatments. Experiment was conducted at the USDA-ARS Irrigated Desert Research Station near Brawley, CA.

		% of total yield by size class — onion diameter				
Irrigation treatment number	Supplemental sprinkling treatments	>12 cm	10.2 to 12 cm	8.2 to 10.2 cm	5.7 to 8.2 cm	< 5.7 cm
T1	Not sprinkled	5	23	47	17	8
	Sprinkled	1	29	49	15	6
T2	Not sprinkled	9	22	46	16	7
	Sprinkled	7	22	51	14	6
T3	Not sprinkled	1	23	48	19	9
	Sprinkled	2	29	45	16	8
T4	Not sprinkled	12	33	39	11	5
	Sprinkled	4	28	48	14	6

beds can be a significant problem in harvest and marketing of fresh-market onions, where small size onions have a limited market value and inconsistency in size increases sorting costs.

FUTURE PLANS: Following removal of the sweet onion crop, the field will remain fallow for the summer months and then be prepared for a winter crop of broccoli as the next rotation crop. Soil sampling will continue to be an important part of this sequence of studies, with samples collected before and after each crop to determine long-term influence of drip irrigation treatments on accumulation of salts and other constituents in the profile.

WATER REQUIREMENTS OF SUBSURFACE DRIP IRRIGATED ONIONS IN THE IMPERIAL VALLEY: III. SOIL WATER CONTENT PROFILES AND MATRIC POTENTIAL MEASUREMENTS

R.B. Hutmacher, R.M. Mead, C.J. Phene, D.A. Clark, R. Swain, T. Donovan, D. Kershaw, S.S. Vail, M.S. Peters, C.A. Hawk, P. Shouse, M. van Genuchten, J. Jobes

OBJECTIVES: The row crop subsurface drip irrigation (SDI) project at the Irrigated Desert Research Station of the USDA-ARS in Brawley, California, is a five-year evaluation of water requirements of select annual crops and the influence of irrigation management on soil accumulations of salts and potentially yield-limiting specific ions. The objectives of this experiment are to study and compare crop responses, irrigation water requirements, and salinity accumulations as affected by SDI systems. Initial plans were to include processing tomatoes, cantaloupe, cotton and lettuce in this study, but plans have been altered considerably to lettuce, cotton, sweet onions and perhaps processing tomatoes and broccoli due to the continued threat of white fly damage associated with the severe infestation plaguing the Imperial Valley since 1991.

PROCEDURES: For a general description of the plot layout and basic operational procedures, see "Water Requirements of Subsurface Drip Irrigated Onions in the Imperial Valley: Operational Procedures" in this volume. There are four irrigation treatments with four replications in a randomized complete block design.

Irrigation Control / Matric Potential Sensor System: Irrigation was controlled to meet some multiple of crop evapotranspiration (ETc) as determined using CIMIS reference evapotranspiration multiplied by a crop coefficient determined using long-term Imperial Valley water use data for onions. Treatments # 1, 2, 3 and 4 were designed to receive approximately 60%, 80%, 100% and 120% of calculated crop evapotranspiration, respectively. but actually received 59%, 76%, 100% and 139% of estimated ETc. Twenty soil matric potential sensors in treatment #3 were used to monitor soil matric potential 0.4 m below the soil surface and 0.1 to 0.15 m laterally from each of five sensors per treatment block.

Soil water content was monitored using neutron attenuation equipment in 3 m deep access tubes located 0.10 m laterally from the drip line and centered between emitters along the drip lines. There were 32 access tubes total, with 2 access tube locations per field replication in each treatment. Additional gravimetric samples were taken to monitor soil water content within the upper 0.6 m of soil.

RESULTS / DISCUSSION: Soil water content in the upper 0.9 m of the profile was relatively high (near field capacity) during the period immediately following the last sprinkler application for establishing the crop. After that time and through the remainder of the growing season, the soil water content as monitored using neutron attenuation indicated that soil water contents below 0.3 to 0.4 m and down to in excess of 1.1 m remained high in all four irrigation treatments.

Gravimetric sampling indicated that low soil water contents developed in the upper 0.15 to 0.3 m of the beds after sprinkling was discontinued. The soil under the outermost plant rows on each bed developed extremely dry zones in the upper 0.15 to 0.2 m of soil by day of year 60, with estimated matric potential values of -0.9 to -2.0 bars (estimated using gravimetric water content and water release curve for the soil).

Sixteen of the original twenty matric potential sensors were still in working order after 2 years of field use. The soil matric potential at the depth of the 5 matric potential sensors in each replication of treatment #3 (designed to be the 100% ETc treatment) consistently indicated that mean soil matric potentials were maintained within the -0.2 to -0.45 bar range in the soil within 0.15 to 0.2 m of the drip laterals (Fig. 1).

The lack of a significant growth or yield response of onions to increases in applied water beyond the treatment #2 level (see other report this volume), coupled with the

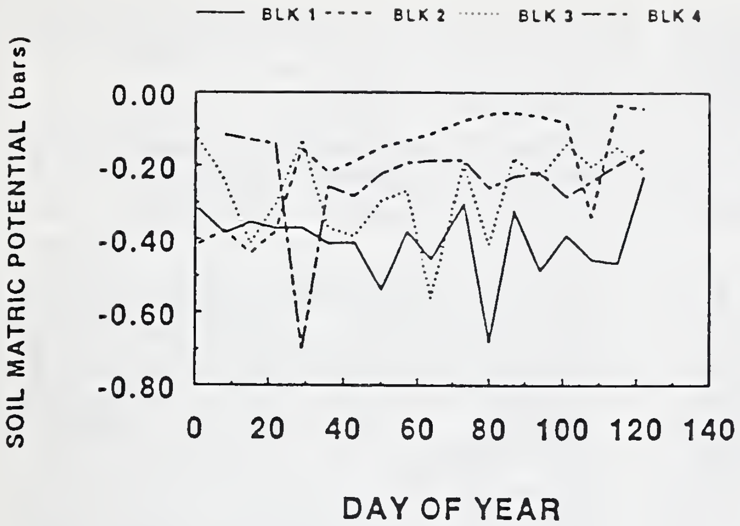


Figure 1. Mean soil matric potential of each block of 5 sensors in irrigation treatment #3 in onions grown under subsurface drip irrigation at the USDA-ARS Irrigated Desert Research Station near Brawley, CA in 1994. Values plotted are averages of measurements from 5 matric potential sensors in each field replication over each 7-day period during the period from the beginning of rapid vegetative growth through onion harvest.

poor growth in the outermost rows of each bed in all treatments indicated a significant problem in meeting water requirements of this onion crop with the drip system as installed and operated. Attempts to increase the drip system operating time to a 4 mm threshold to move the water further vertically and laterally were somewhat successful, but still did not maintain higher soil water content in the surface 0.2 m of soil under the outer areas of each bed. Other options need to be evaluated to produce greater success in subsurface drip-irrigated onions in this soil.

FUTURE PLANS: The next crop to be grown in this field will be broccoli, planted in the fall of 1994. The sensors will be monitored in this season, as before.

WATER REQUIREMENTS OF SUBSURFACE DRIP IRRIGATION IN THE IMPERIAL VALLEY OF CALIFORNIA: FORAGE ALFALFA - SYSTEM OPERATION AND MANAGEMENT

C.J. Phene, R.B. Hutmacher, R.M. Mead, D.A. Clark, R. Swain, T. Donovan, D. Kershaw, M.S. Peters, C.A. Hawk, P. Shouse, M. van Genuchten, J. Jobes, J. Rhoades

OBJECTIVES: The alfalfa subsurface drip irrigation/furrow irrigation experiment at the Irrigated Desert Research Station in Brawley, CA is a five-year evaluation of alfalfa water requirements and the influence of irrigation management on soil accumulations of salts and potentially yield-limiting specific ions. This experiment focuses on the comparison of crop responses, irrigation water requirements, and salinity accumulation as affected by subsurface drip versus furrow irrigation. In addition, the influence of two drip lateral spacings (1.02 m versus 2.04 m) will be evaluated.

PROCEDURES: Alfalfa was planted in Fall/Winter of 1993 in a Holtville silty clay soil at the USDA-ARS Irrigated Desert Research Station near Brawley, CA. The irrigation water used in the study was from the Colorado River canal system, with an average electrical conductivity of 1.15 dS m^{-1}, pH of 7.4 to 7.7, bicarbonate concentration of 2.2 to 2.7 mmol L^{-1}, and chloride concentration of 2.5 to 3.6 meq L^{-1}.

The original experiment was operated from January 1991 through December 1992, after which time the drip irrigation system was substantially modified. The reason for the modification were problems with development of "wet" and "dry" surface areas within the field (about 3% of the field area affected). It was determined that the "wet" areas resulted from both too shallow lateral placement and a limited number of malfunctioning emitters. The "dry" areas were extremely limited in the size of areas affected. Evaluations indicated the cause was fine silt deposition caused by filtration problems and some missing emitters. Root intrusion was not a significant cause of emitter plugging.

The original lateral installation depth was about 40 to 45 cm, while the new system was installed in 1993 with laterals at a depth of 63 to 70 cm below the soil surface, with the drip laterals placed below the center of each bed, on 1.02 m and 2.04 m wide beds. Two different types of drip tubing were used with each row spacing treatment: (a) pressure-compensating in-line emitters on 20 mm tubing; and (b) turbulent-flow in-line emitters made with herbicide (trifluralin)-impregnated plastic. Both emitter types have a nominal flow of 2 L h-1 at 18 to 20 psi, with 1.02 m emitter spacing.

The first crop grown following the drip lateral installation was sudangrass in the summer and fall of 1993 (see additional report on sudangrass in this volume). Alfalfa was planted during the fall of 1993 and established using 135 mm of sprinkler irrigation for germination and crop establishment. The current lateral configuration will be evaluated at least during the 1993 through 1995 calendar years. As during the previous phase of this experiment, Mr. Dean Currie of Stephen Elmore Farms in the Imperial Valley is cooperating with us in helping match furrow plot irrigation scheduling with typical Imperial Valley alfalfa water management practices on similar soils.

RESULTS: *Summary of Results Prior to Drip System Installation.* Results from alfalfa studies prior to 1994 were summarized in previous volumes of this annual report, and only a brief summary will be offered here. Total water use (applied water plus soil water depletion plus rainfall) (from April 1991 planting through December of 1992) averaged about 2850 mm in the subsurface drip irrigated plots versus about 3100 mm in the furrow plots. Over the 1991 and 1992 seasons, evapotranspiration was about 6 to 10% lower in drip than in furrow-irrigated plots. Average forage yields during the same period were about 22% higher in drip plots than in furrow-irrigated plots, averaging about 35 T ha-1 in the drip plots versus 29 T ha-1 in furrow plots

during the same 18 month period of 1991-1992.

In the furrow irrigation plots, typical practices for the Imperial Valley were followed, which included application of the last irrigation of each harvest cycle 5 to 8 days prior to harvest. The first irrigation of each cycle occurred immediately after bale removal. The problems with "wet" surface soil areas in drip plots were found to disrupt harvest operations, therefore, irrigations in the drip plots during the "harvest dry-down" period were reduced to 25% to 50% of lysimeter water applications (a field lysimeter was planted with alfalfa and water use under non-water-limiting conditions was measured).

Second Planting - 1994 Water Applications, System Operation and Yields. Up through the time period for preparation of this report (early summer 1994), the alfalfa crop establishment went very well, with a good crop stand achieved. Water applications and water use were similar in the furrow and drip plots through June of 1994, while yields were about 12 to 17% higher in the drip irrigated plots.

It has not been necessary to scale back irrigations in the drip plots during the harvest cycle due to a lack of surface "wet" spots. To date (early summer, 1994), the deeper lateral installation depth has eliminated surface "wet" areas and harvest equipment trafficability problems. The more severe conditions (high potential ET) during the summer period of 1994 will be a more severe test of the ability of the drip system to supply crop water requirements even when installed at 63 to 70 cm depth. Those results will be summarized in next year's annual report.

As in the previous phase of this experiment, water applications in the furrow plots are limited in the amount per application (about 58 to 105 mm) by low infiltration rates and reduced infiltration opportunity time. Despite shallow (10 cm) shanking of each furrow following each harvest, water infiltration and furrow applications typically decline significantly with each subsequent irrigation following each harvest and shanking. It is difficult to apply water in amounts greater than about 95% of the lysimeter-measured ET without risking scalding injury due to prolonged presence of surface water.

FUTURE PLANS: An extensive soil sampling will be conducted during the Winter of 1994 to identify potential problems with salt accumulations within the root zones. Quarterly soil sampling to a depth of 90 cm across the beds will be started in the fall of 1994 to more accurately track seasonal changes in salinity distribution.

EFFECT OF SOIL SELENIUM CONCENTRATION ON SELENIUM VOLATILIZATION IN COTTON

S. Downey, G. Bañuelos, and S. Akohoue

OBJECTIVES: To compare effects of three soil selenium (Se) concentrations added as selenate on rate of Se volatilization in cotton.

PROCEDURES: Seeds of cotton (*Gossypium hirsutum* var. GC 510) were germinated in flats containing vermiculite potting soil. After ten days, seedlings were transplanted into 18 L pots containing soil (Panoche fine-loamy, mixed [calcareous], Thermic typic torriorthents) amended with four different concentrations of Se: 0, 0.25, 1.0, and 2.5 mg Se kg^{-1} soil added as sodium selenate. Each pot was thinned to four seedlings. There were three replications and one control pot for each Se treatment. Control pots contained soil amended with respective Se treatment but no plants. After forty-five days, each 18 L pot from each Se treatment was placed inside a volatile Se collection chamber for 4 days, which was housed within an environmental growth chamber. Every seven days this collection process for volatile Se was repeated until final harvest of cotton for a total of six collection times for each treatment. Conditions within the environmental growth chamber were held at a constant 30 degrees C with a photoperiod of 16/8 h. light and dark (850 micromol/m^2/sec.). Volatile Se collection chambers were constructed of transparent acrylic and measured 30 cm x 30 cm x 60 cm. Each chamber was equipped with a circulation fan and an exhaust port filled with eight pieces of activated charcoal filter each measuring 7.5 cm x 5 cm. The fan directed the air within the chamber through the charcoal trap and out the exhaust port, trapping volatilized Se on the activated charcoal. Filters were removed for analysis after 4 days. Volatilized Se was extracted from the charcoal filters by nitric acid/hydrogen peroxide digestion described elsewhere (Ann. Rpt. 1993; *Extraction and Analysis of Volatilized Selenium from Activated Charcoal Filters*) and analyzed by atomic absorption spectrophotometry with continuous hydride generation. Plant tissue Se and total soil Se were analyzed as described elsewhere (Ann. Rpt. 1993; *Comparison of Wet Acid Digestion by Microwave or Block Digestor on the Recovery of Selenium and Boron in Plant Samples*).

RESULTS: Preliminary results show that there was no significant increase in the rate of Se volatilization in cotton with increased soil Se concentration nor with increased concentrations of Se in the plant tissue (Table 1).

Table 1. Recovery of plant tissue Se and volatile Se calculated on per day basis for cotton grown in selenate-enriched soils.†

Soil Se Concentration (mg Se kg^{-1} soil)	Cotton plants	Se recovered in: Charcoal filter (µg Se pot^{-1} day)	Plant tissue (mg Se kg^{-1} DM)
Treatment I			
0	yes	0	<1
0	no‡	0	NA§
Treatment II			
0.25	yes	0.43(0.03)	9(2)
0.25	no	0.09(0.00)	NA
Treatment III			
1.0	yes	0.52(0.05)	40(4)
1.0	no	0.13(0.00)	NA
Treatment IV			
2.5	yes	0.53(0.09)	135(9)
2.5	no	0.14(0.00)	NA

†Values represent the mean amount of volatile Se calculated per pot per day from six different collection times followed by standard error in parenthesis. A minimum of 18 samples comprised each value.

‡Control soils consisted of Se treatment without plants were also measured for volatile Se.

FUTURE PLANS: Complete analyses for volatile Se. Conduct additional experiments with different species of Se, salinity levels and water stress levels, and evaluate their influence on the ability of cotton to volatilize Se.

EXTRACTION AND ANALYSIS OF VOLATILIZED SELENIUM FROM ACTIVATED CHARCOAL FILTERS

S. Downey, G.S. Bañuelos, and S. Akohoue

OBJECTIVES: To develop a reliable method of extraction and analysis of volatilized selenium collected by activated charcoal filters.

PROCEDURES: A wet acid digestion procedure was developed for extracting volatile selenium (Se) from charcoal filters. A series of tests were conducted to examine the feasibility of extracting volatile Se from eight charcoal filters using the same HNO_3/H_2O_2 wet acid digestion methods already used for Se extraction from plant material (Ann. Rpt. 1993; *Comparison of Wet Acid Digestion by Microwave or Block Digest or on the Recovery of Se and B in Plant Tissue*). This method has the major advantage of using smaller quantities of H_2O_2 than a H_2O_2 percolation/extraction method used elsewhere for extracting volatile Se from activated charcoal filters. Filter samples (0.25 to 0.50 gm) obtained from other volatile Se experiments described elsewhere (Ann. Rpt. 1993; *Effect of Soil Selenium Concentrations on Selenium Volatilization in Cotton*) were digested with 6 ml concentrated HNO_3 and 0.1 ml cerric NH_4NO_3 using an automated digestion block. Samples in the digestion tubes were covered with small funnels and heated at 110°C for 8 hrs. After cooling, 0.1 ml and 0.2 ml increments of 30% hydrogen peroxide were slowly added to all samples to ensure oxidation of Se to the Se (VI) valence state. The small increments of H_2O_2 were necessary to prevent boiling over. Samples were then heated to 110°C for 45 minutes and allowed to cool. Due to the interfering properties of the remaining nitrates in solution, small increments (0.1 - 0.2 ml) of formic acid were added to eliminate excess H_2O_2 and HNO_3. Following digestion at 130°C for 30 minutes and a cooling period of 2 hr, 1 ml of hydroxylamine hydrochloride was added, followed by 30 ml of concentrated HCL, to ensure reduction of Se (VI) to Se (IV). Samples are shaken and allowed to stand overnight; this allows for all potential interfering particles to collect at the bottom of the digestion tubes. Selenium was then quantified by a Varian Model AA-975 Series spectrophotometer with Varian Model VGA-76 hydride generator and Varian Model 55 Programmable Sample Changer.

RESULTS: Preliminary results show that Se values determined after wet acid digestion were consistently higher than those derived from the H_2O_2 percolation method (Table 1). Subsamples sent to UC Berkeley to compare recovery rate of volatile Se from activated charcoal filters (UC Berkeley uses H_2O_2 percolation extraction technique). Volatile Se adsorbed to the inside charcoal filters is more difficult to extract when using the H_2O_2 percolation extraction method.

FUTURE PLANS: Complete analyses of charcoal samples for volatile Se. Growth chamber and field experiments will be conducted to determine the contribution of Se volatilization by plants to bioremediating Se in contaminated soils.

Table 1. Comparison of the recovery of volatile Se from activated charcoal filters with total acid digestion and the hydrogen peroxide extraction methods.†

Method of recovery	Selenium recovery in:							
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8
	(μg Se filter^{-1})							
Total‡	70(5)	47(6)	36(3)	40(5)	38(3)	27(3)	19(2)	29(3)
H_2O_2§	56(4)	28(2)	17(3)	16(4)	10(1)	21(3)	12(1)	26(3)

†Values represent the mean from three replications followed by standard error in parenthesis.
‡Total acid digestion with HNO_3, H_2O_2 and HCl.
§H_2O_2 extraction method.

SURVEY OF INSECTS ATTRACTED TO DIFFERENT PLANT SPECIES USED FOR REMEDIATION OF BORON-LADEN SOILS

G.S. Bañuelos, S. Tebbets, F. Cardenas,
S. Zambrzuski, P. Samra, and P. Vail

OBJECTIVES: Identify the insects which are inhabiting Indian mustard, kenaf, birdsfoot trefoil, and tall fescue, which are used for lowering B levels in soil.

PROCEDURE: A two year study is being conducted to collect insects inhabiting different plant species grown to bioremediate boron-laden soils on Three Way Farms, Los Banos, California. The treatment design was a complete randomized design with each treatment replicated three times. Treatments consisted of the following plant species growing on adjacent 20 m^2 plots: *Brassica juncea* (Indian mustard), *Festuca arundincea* (tall fescue), *Lotus corniculatus* (birdsfoot trefoil), and *Hibiscus cannabinus* (kenaf). All plots were managed and sprinkle-irrigated identically on the B-laden soil. Forty-five d after emergence, each plot was sampled weekly at 10 A.M. for insects using an insect sweep net. There were a total of 15 sampling dates throughout the designated growing season. Each sample consisted of eight sweeps progressing from the outside of the plot towards the middle. Collected insects were placed in a glass jar, frozen, stored in alcohol, and identified later.

RESULTS: Due to the large number of insects attracted to the flowering species (birdsfoot trefoil, kenaf, and Indian mustard), in-depth identification of these species will require more time. Consequently the initial screening consisted of separating the insects into a general insect classification (Table 1) and separating into "beneficials" and "predators".

FUTURE PLANS: The in-depth identification of insects is actively being pursued. Insect sampling will continue to take place for the second year. A future study will include planting only those plant species for soil B remediation which attract the fewer potentially harmful insects.

Table 1. General survey of the predominate insects habitating different crop species used for the bioremediation of boron-laden soils.*

Crop Species:	Insects:
Birdsfoot trefoil	Lygus, Western flower thrips, Aceratagallia sp. (Hopper) Family name – Cicadellidae, Colladonus mountanus (Hopper), Empoasca sp. (Hopper).
Indian mustard	Lygus, Western flower thrips, Flea beetle, Grass Bug nymphs and adults – Family name – Rhopalidae, Empoasca sp. (Hopper), Stink bug.
Tall fescue	Amblysellus grex (Hopper), Western flower thrips, Euscelis obsoletus (Hopper). Grass Bug adults.
Kenaf	Lygus, Hyperaspis sp. Family name – Coicinellidae, Empoasca sp., Aceratagallia sp. Family name – Cicadellidae (Hopper), Salt Marsh caterpillar.
Cotton	Lygus, Empoasca sp. (Hopper), Leaf beetle Family name – Chrysomelidae.
Fallow (weeds)	False chinck bug, Western flower thrips.

*Insects are not ranked in order of predominance. Predominance varies with time of year.

USING TALL FESCUE TO REMEDIATE BORON-LADEN SOILS

G.S. Bañuelos, L. Wu, S. Zambrzuski, and S. Akohoue

OBJECTIVES: Evaluate the ability of tall fescue to simultaneously tolerate and remove extractable soil B.

PROCEDURES: A multiple year field study was conducted on native B-laden soils (>5 mg extractable B/L) on Three Way Farms near Los Banos, California. The treatment design was a complete randomized block with each treatment replicated six times. Treatments consist of "cropped plots" and "bare plots" (controls; no plants). Each cropped plot (17m x 17m) was drill planted to *Festuca arundincea* (tall fescue) to a depth of 10 mm at a rate of 10 kg/ha. Access tubes were installed in each plot to a depth of 2 m. All plots were managed and sprinkle-irrigated with California aqueduct water (E_c <0.8 dSm^{-1}) based on weather data acquired through the CIMIS system in Los Banos and readings taken every 10 d with the neutron probe. Four soil samples were collected from each respective depth (0-45 and 45-90 cm) within each plot from May 1 and October 15, 1992 and 1993, respectively. Preplant soil concentrations of selected parameters are shown in Table 1. Plants were mechanically swathed to a height of 20 cm every 60 d during the growing season for a total of three clippings each year. Prior to each swathing, subsamples of tall fescue were hand clipped from four, one meter squared sampling sites within each plot. Samples were washed, oven-dried at 50°C, weighed, and ground in a Wiley mill. Plant tissue was wet acid digested with nitric acid/hydrogen peroxide/HCl and water soluble soil B was extracted from a saturated paste. All B samples were analyzed using an Emission Spectrometer Inductively Coupled Plasma (Perkin Elmer Plasma 2000).

RESULTS: Concentrations of B measured in the harvested plant material seldom exceeded 130 mg B kg^{-1} DM (Table 2). Yields of each clipping increased with each subsequent clipping and with the subsequent year (Table 2). Preliminary data from the first two years indicate that tall fescue can both be successfully grown on high-B soils and positively contribute to the long-term management of reducing soil B levels (Table 3). Both levels of extractable and total soil B were lower in cropped plots than 'control plots'.

FUTURE PLANS: Although tall fescue planted for environmental reclamation is not the long-term solution to removing high levels of soil B, the planting of tall fescue in conjunction with more efficient irrigation practices and drainage water management may ameliorate the negative effects that high soil B exerts on plants. Future studies will evaluate the long term effects of growing tall fescue for multiple years on the lowering of soil B levels. Moreover, animal forage studies will be conducted with harvested tall fescue used for B remediation. A manuscript has been submitted.

Table 1. Mean acid soluble soil concentrations of selected trace elements at preplant in 1992 and 1993 in the soil profile (0–90 cm) of all plots.*

	Total Concentrations of Selected Elements:								Other Parameters	
Year	Zn	Cd	Mn	Cu	Mo	Se	Fe	Al	pH	EC
	(mg kg^{-1} soil)						(%)			(dSm^{-1})
1992	50(2.1)	8.1(0.6)	600(65)	20(5.1)	1.0(0.1)	0.7(0.1)	1.1(0.2)	3.9(0.4)	7.8(0.3)	2.8(0.1)
1993	47(2.2)	6.4(0.9)	727(71)	24(4.8)	0.8(0.1)	0.5(0.1)	1.0(0.4)	4.2(0.3)	7.7(0.3)	3.2(0.1)

*Values presented represent the mean concentration from a minimum of 100 samples for each year followed by the standard error in parenthesis.

Table 2. Dry matter (DM) yield and tissue B concentrations in clippings from tall fescue during 1992 and 1993 growing period.*

Year	Clipping	DM yield ($g\ m^{-2}$)	Boron Concentrations in: Shoot ($mg\ kg^{-1}$ DM)	Root
1992				
	1	262	88	NA
	2	776	105	NA
	3	872	110	57
1993				
	1	1211	118	NA
	2	1391	121	NA
	3	1494	121	61
	**S.E.	26	2.3	2.0

*Values presented represent the mean yield from a minimum of 24 individual square meter sampling sections.
**Standard error.
NANot applicable.

Table 3. Changes in soil B concentrations throughout the growing seasons in plots planted and not planted to tall fescue in 1992-93.*

Treatment in plots	Time of sampling	Soil Depth (cm)	Soil B concentrations: Extractable B ($mg\ B\ L^{-1}$)	Total B ($mg\ B\ kg^{-1}$ soil)
1992				
Control	Preplant	0–45	5.0(0.4)	37.6(3.3)
Control	Postharvest	0–45	4.3(0.4)	36.5(3.1)
Cropped	Preplant	0–45	5.9(0.5)	37.6(3.3)
Cropped	Postharvest	0–45	4.3(0.4)	35.2(3.3)
1992				
Control	Preplant	45–90	6.1(0.5)	38.5(1.7)
Control	Postharvest	45–90	6.0(0.4)	37.3(1.8)
Cropped	Preplant	45–90	5.3(0.4)	42.6(2.5)
Cropped	Postharvest	45–90	4.3(0.3)	40.4(2.3)
1993				
Control	Preplant	0–45	4.2(1.6)	37.6(3.3)
Control	Postharvest	0–45	4.0(0.4)	35.2(3.3)
Cropped	Preplant	0–45	4.1(0.4)	41.4(2.4)
Cropped	Postharvest	0–45	3.5(0.4)	39.3(2.0)
1993				
Control	Preplant	45–90	6.1(0.4)	39.6(2.6)
Control	Postharvest	45–90	6.2(0.4)	38.2(2.7)
Cropped	Preplant	45–90	4.2(0.4)	41.4(2.4)
Cropped	Postharvest	45–90	3.7(0.4)	39.3(2.0)

*Values presented represent the mean concentrations from all six plots (48 samples) for each treatment, respectively, followed by the standard error in parenthesis.

EVALUATE THE EFFECT OF CROP ROTATION ON MANAGING BORON AND SELENIUM LEVELS IN POOR QUALITY SOILS

G.S. Bañuelos, L. Wu, P. Beuselinck, S. Zambrzuski, and S. Akohoue

OBJECTIVES: To determine the extent to which crop rotation with selected B-tolerant species contributes to the reduction of soil B levels.

PROCEDURE: A multiple year crop rotation study with *Brassica juncea* (Indian mustard), *Festuca arundincea* (tall fescue), *Lotus corniculatus* (birdsfoot trefoil), *Hibiscus cannabinus* (kenaf), and bare plots (without plants) is being conducted on Three Way Farms near Los Banos, California. The treatment design was a complete randomized design with each treatment replicated a minimum of three times on 10 x 10 m plots. The five treatments for three years consisted of the following plant species planted in crop rotation for three years:

Trt. *I*: 1st year (Indian mustard), 2nd year (Indian mustard), 3rd year (tall fescue).

Trt. *II*: 1st year (tall fescue), 2nd year (tall fescue), 3rd year (tall fescue).

Trt. *III*: 1st year (kenaf), 2nd year (kenaf), 3rd year (tall fescue).

Trt. *IV*: 1st year (kenaf), 2nd year (birdsfoot trefoil), 3rd year (birdsfoot trefoil).

Trt. *V*: 1st year (bare plot), 2nd year (bare plot), 3rd year (bare plot).

Soil samples were taken from each plot as already described (Ann. Rpt., 1993; *Comparison of Wet Acid Digestion by Microwave or Block Digestor on the Recovery of Selenium and Boron in Plant Samples*) during the designated growing season between May 1 (preplant) and October 15 (harvest) of each year. Treatments were sprinkle-irrigated based on data accumulated by CIMIS and weekly neutron probe readings taken in two locations of each plot. Plant samples of each species were hand-clipped from four one meter squared sampling sites within each plot for each treatment. Both plant and soil samples were prepared and analyzed for Se and B as already described (Ann. Rpt., 1993; *Comparison of Wet Acid Digestion by Microwave or Block Digestor on the Recovery of Selenium and Boron in Plant Samples*).

RESULTS: Preliminary data for soil samples the first two years are shown in Table 1. For the first two years, the planting of *B. juncea* followed by *B. juncea* appears to be the most effective crop rotation in lowering soil extractable B and total soil Se. In comparison to bare plots, however, all crop rotations lowered levels of B and Se in the soil.

FUTURE PLANS: The study will be continued in 1994. Future studies will include incorporating generally accepted agronomic crops, i.e., alfalfa, cotton tomatoes, in the crop rotation with the tested plant species used to lower soil B and Se. Moreover, deeper depths of the soil profile will be analyzed for Se and B after the perennial species are eventually planted in each treatment. A manuscript will be prepared and submitted after 1994.

Table 1. Mean preplant and postharvest soil concentrations of extractable B and total Se between 0 to 75 cm for different crop rotations during 1992–1994.

Treatment* #	Plant species	Extractable B Preplant (mg L^{-1})	Extractable B Harvest (mg L^{-1})	Total Se Preplant (mg kg^{-1} soil)	Total Se Harvest (mg kg^{-1} soil)
1992					
I	*B. juncea*	7.0	4.8	1.10	0.75
II	*F. arundincea*	6.6	5.4	0.98	0.84
III	*H. cannabinus*	6.8	5.1	1.20	0.98
IV	*H. cannabinus*	5.4	4.3	0.96	0.82
V	Bare plot	6.2	5.8	1.20	1.13
1993					
I	*B. juncea*	5.1	4.4	0.82	0.68
II	*F. arundincea*	5.0	4.2	0.91	0.78
III	*H. cannabinus*	4.7	4.1	1.04	0.83
IV	*L. corniculatus*	4.6	4.3	0.79	0.64
V	Bare plot	5.6	5.4	1.17	1.13
1994					
I	*F. arundincea*	NA	NA	NA	NA
II	*F. arundincea*	"	"	"	"
III	*F. arundincea*	"	"	"	"
IV	*L. corniculatus*	"	"	"	"
V	Bare plot	"	"	"	"

*Values presented represent the means from a minimum of 36 soil samples taken from 0–75 cm in the soil.

**Each treatment number represents three replicates.

NANot applicable; currently growing.

THE EFFECT OF SODIUM 2,3-DICHLOROISOBUTYRATE (DCB) ON THE CARBOHYDRATE PRODUCTION AND BIOMASS IN FIELD-GROWN INDIAN MUSTARD

G.S. Bañuelos, L.H. Aung, D. Fouse, S. Akohoue, and S. Zambrzuski

OBJECTIVE: To determine if the growth regulator-DCB modifies the production of carbohydrates/soluble sugars in Indian mustard and thus promotes the ability of Indian mustard to absorb Se from Se laden soil.

PROCEDURE: Indian mustard (*Brassica juncea*) was planted on Ramona sandy loam at the USDA facility in Fresno, California, during 1992-93. The field site was divided into sixteen plots (4 X 14 m, respectively). Beds were spaced 1 m apart from center to center. Seed were planted with Planet Jr. to a depth of 2 cm and spaced 15 cm apart. Due to ample moisture in the soil profile resulting from winter rains, only a total 140 mm of water was sprinkle-irrigated. The two treatments consisted of: 1) foliar application of 12 mM DCB; 2) foliar application of deionized water (control plots). Thirty days after plant emergence, the DCB plots were carefully hand-sprayed (to avoid drifting), while the control plots were sprayed with the same volume of deionized water (containing no DCB). Seven days later, DCB and the deionized water were reapplied to the respective treatments. Forty-five days after the second application of DCB and deionized water, sixteen to twenty plants were harvested from each plot. Each harvested plant was washed and separated into the following organs: upper and lower stalk, young and old leaves, and roots. Samples were dried at 45°C for 7-10 days, weighed, and ground in a stainless steel Wiley mill equipped with a 1 mm mesh screen. Preparation of ground samples for carbohydrate/soluble sugar extraction consisted of the following: 1) one gram samples were extracted with 10 ml 80% ethanol at 80°C; 2) volume was readjusted to 10 ml; 3) three ml aliquot of the supernatants were taken and evaporated to dryness. The dried residues were suspended into 1.5 ml of HPLC grade water and transferred into 1.5 ml centrifuge tubes. After centrifugation, 1 ml of the aqueous solution was filtered prior to the analysis of soluble sugars by HPLC. Sucrose, glucose, and fructose were qualitatively and quantitatively determined in replicates of five using a Hewlett-Pachard HPLC Model 5020. The above sugars were separated through a 300 x 7.8 mm Aminex carbohydrate HPX-87°C column. The column temperature was maintained at 80°C using a Jones chromatography column oven. The solvent was PHLC grade water at a flow rate of 0.7 ml/min.

RESULTS: Preliminary data show a higher soluble sugar content in all organs from plants harvested from the "control" plots in comparison to the DCB treated plots (Figures 1a-c). Among the sugars evaluated, sucrose was most significantly affected by the foliar application of DCB. Dry weight yield was slightly reduced in most organs of the DCB treated plants (Figure 2), although the DCB sprayed plants appeared to remain longer in the vegetative stage before going into the generative stage. Moreover, increased branching was observed in the DCB sprayed plants (data not reported).

FUTURE PLANS: Continue the sugar analyses and evaluate concentrations of tissue Se within the plant and its relation to sugar content and sugar type. Future studies will evaluate the Se uptake efficiency of DCB sprayed plants, due to the two visually observed effects; increased branching and delayed bloom. If the DCB sprayed plants can remain longer in the vegetative stage (before bloom and leaf abscission occur) by manipulating the sugar content (other parameters may be affected) then more Se may be removed from the soil by bioremediation. A manuscript is currently in preparation.

Figures 1a–c. The effect of sodium 2,3 Dichloroisobutyrate (DCB) on the carbohydrate production in different plant organs of Indian mustard. Plant organs are represented in the graphs by: RT (roots); YL (young leaves); OL (old leaves); YS (young stems); OS (old stems).

Fig. 1a

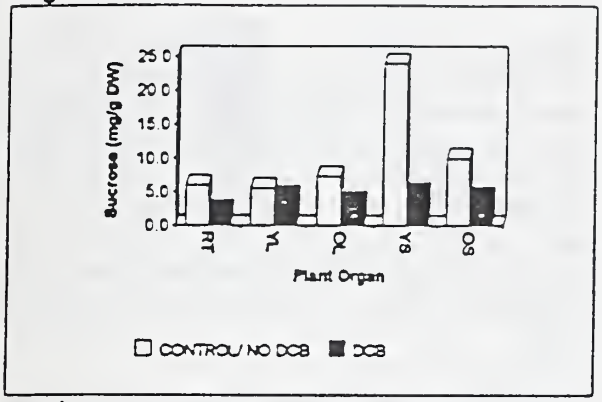


Fig. 1b

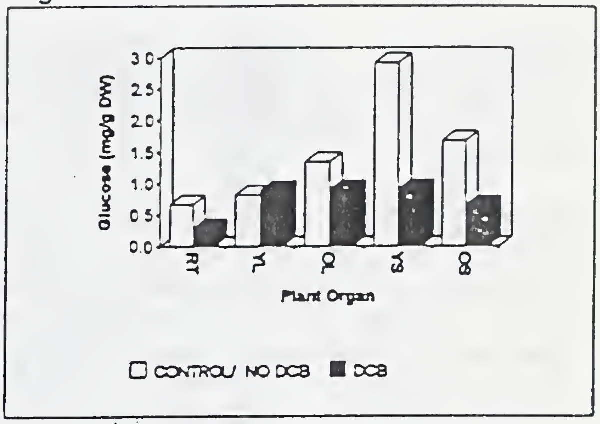


Fig. 1c

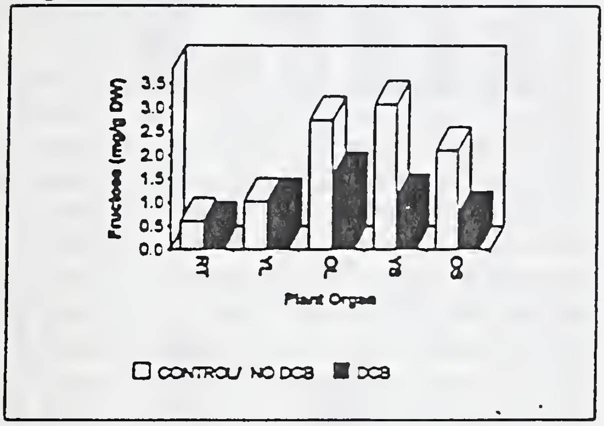
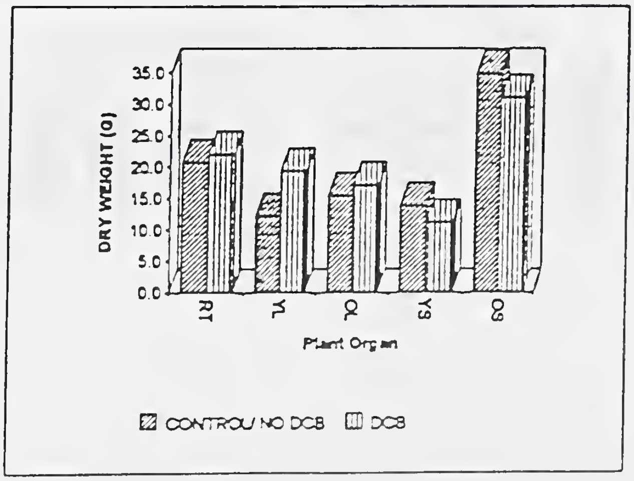


Figure 2. The effect of sodium 2,3 Dichloroisobutyrate (DCB) on the dry weight of different organs of Indian mustard. Plant organs are represented in the graphs by: RT (roots); YL (young leaves); OL (old leaves); YS (young stems); OS (old stems).



COMPARISON OF WET ACID DIGESTION BY MICROWAVE OR BLOCK DIGESTOR ON THE RECOVERY OF SELENIUM AND BORON IN PLANT SAMPLES

G.S. Bañuelos and S. Akohoue

OBJECTIVES: To evaluate microwave digestion and block digestion on the recovery of selenium and boron in plant materials.

PROCEDURES: *Microwave digestion* Plant tissue digestions were performed in 120 ml Teflon-lined digestion vessels. There were a minimum of 50 replicates per treatment. Treatments were based upon the following: 1) influence of sample predigestion; 2) different microwave energy profiles; 3) different pressures; 4) different chemical reagents; and 5) different time settings (Table 1). Each treatment was systematically modified and its effect was evaluated on the recovery of Se and B at low and high concentrations of Se and B in plant tissue. Based on preliminary evaluation, a predigestion time of 4 hrs. was used for the Se treatments and 30 min. for B treatments. Both elements were determined in NIST Standard Reference Material for both Se and B (low concentrations of Se and B) and in 20-mesh ground *Brassica juncea* plant material (high concentrations of Se and B; obtained from a previous experiment).

Block digestion Nitric acid-hydrogen peroxide-hydrochloric acid and nitric acid-sulfuric acid-hydrochloric acid were used to digest plant material in 75 ml volumetric glass digestion tubes on the block digestor for Se and B determination, respectively.

Analyses Selenium was determined in plant samples digested from both microwave and digestion block using an Atomic Absorption Spectrophotometer equipped with an automatic vapor accessory. All measurements were made at the most sensitive resonance line (196.0 nm) using an air/acetylene flame. Boron was determined in plant samples digested from both microwave and digestion block using an Emission Spectrometer-Inductively Coupled Plasma (Perkin Elmer Plasma 2000).

RESULTS: Microwave digestion is at least 4 hours faster than block digestion. However, the recovery rates for Se and B may be 20-30% lower by microwave digestion if there is no predigestion of plant material and if the inappropriate volume and combination of chemical reagents are used for digestion as seen in Figures 1A - 5B. The optimal combination of the tested parameters for the greatest recovery of Se and B by microwave digestion are as follows: for Se, 0.25 g of sample material is predigested for 4 hours with 2 ml HNO_3, 2 ml H_2O_2, and 1 ml H_2O; the microwave is set al 95% power and pressure at 150 psig for 30 min. For B, 0.25 g of sample material is predigested for 30 min. with 0.5 ml HNO_3 and 2.5 ml H_2O_2. The microwave is then set at the first stage at 50% power and pressure at 150 psig for 15 min. followed by the second stage at 90% power, and pressure set at 150 psig for 30 min.

FUTURE PLAN: The optimal treatment for microwave digestion (detailed in results) will be used for plant sample preparation for Se and B determination in our laboratory. A manuscript describing the comparative study has already been submitted.

Figures 1A-5B. Influence of different microwave settings on the recovery of Se and B in plant samples.

Figure 1A.

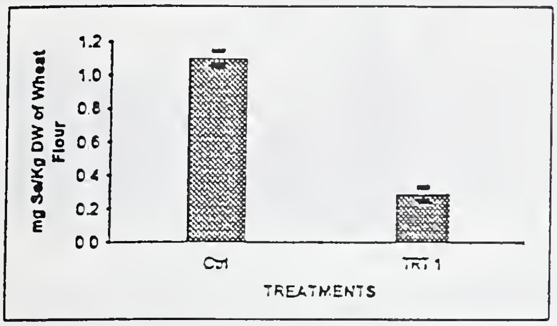


Figure 1B.

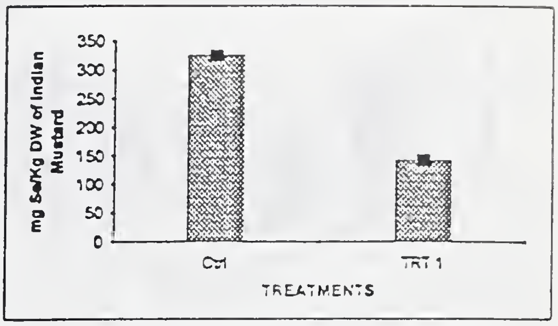


Figure 2A.

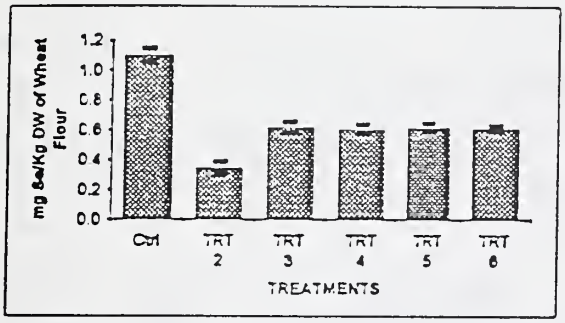


Figure 2B.

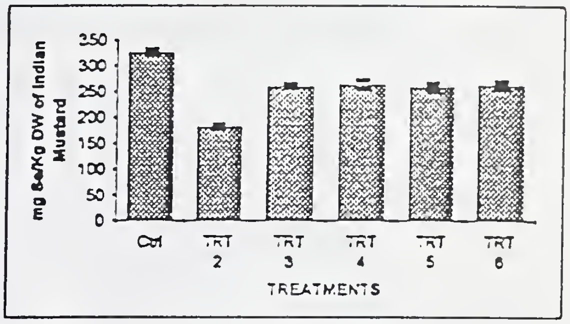


Figure 3A.

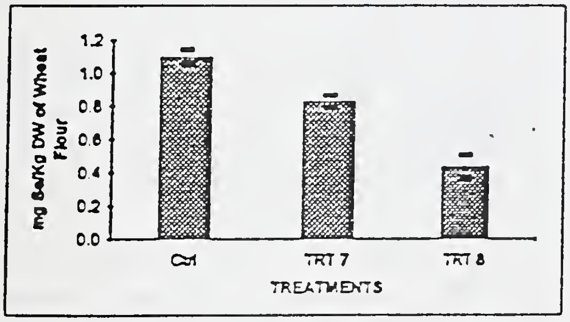


Figure 3B.

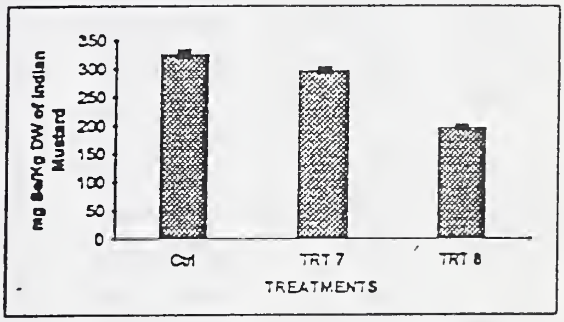


Figure 4A.

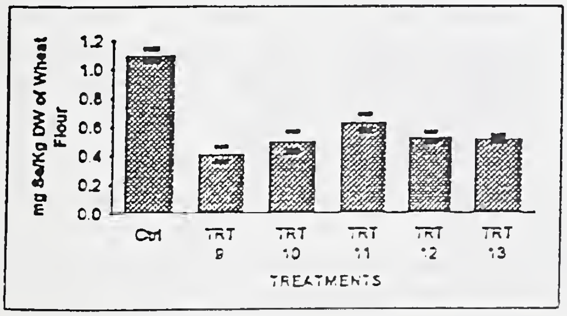


Figure 4B.

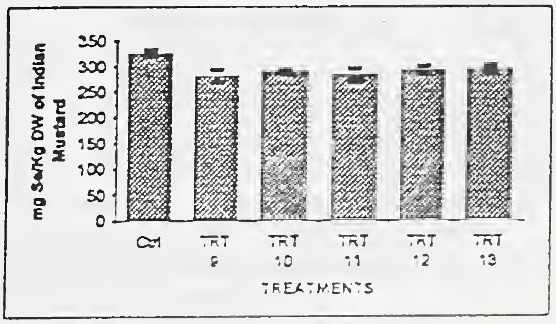


Figure 5a.

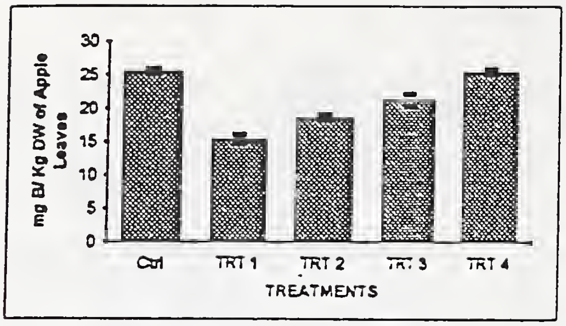


Figure 5b.

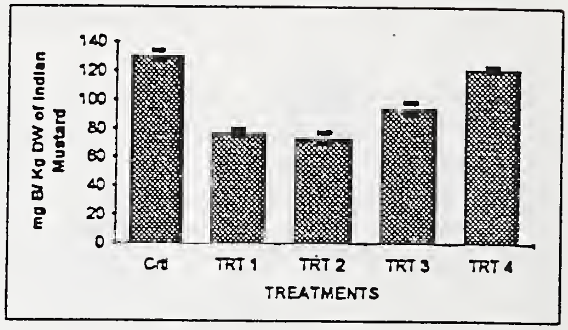


Table 1. Microwave parameter settings for figures 1a to 5b.

MICROWAVE PARAMETER SETTINGS

Treatment	HNO_3	H_2O_2 (ml)	H_2O	Pre-digestion	Power (Time) % (min)			
Fig. 1a–4b. for B analyses								
1	10.0	0.0	0.0	no	85(10)	85(10)	85(10)	0(10)
2	0.5	2.5	0.0	no	50(05)	90(08)	0(10)	0(00)
3	1.0	2.0	0.0	yes	"	"	"	"
4	3.0	3.0	0.0	yes	"	"	"	"
5	2.0	2.0	0.0	yes	"	"	"	"
6	0.5	2.5	0.0	yes	"	"	"	"
7	2.0	2.0	1.0	yes	95(30)	"	"	"
8	2.0	2.0	1.0	no	95(30)	"	"	"
9	0.5	2.5	0.0	yes	50(15)	"	"	"
10	1.0	2.0	0.0	yes	"	"	"	"
11	2.0	2.0	1.0	yes	"	"	"	"
12	3.0	3.0	0.0	yes	"	"	"	"
13	2.0	2.0	0.0	yes	"	"	"	"
Fig. 5a–5b. for Se analyses								
1	10.0	0.0	0.0	no	85(06)	85(06)	85(12)	0(00)
2	10.0	2.5	0.0	yes	95(30)	0(10)	0(00)	"
3	0.5	2.5	0.0	no	50(05)	90(08)	0(10)	"
4	0.5	2.5	0.0	yes	50(15)	90(30)	0(30)	"

Control: Block digestion

REMEDIATION OF SELENIUM AND BORON CONTAMINATED SOIL WITH *LOTUS CORNICULATUS* L. (BIRDSFOOT TREFOIL)

G.S. Bañuelos, S. Zambrzuski, S. Akohoue, and P. Beuselinck

OBJECTIVES: To determine if birdsfoot trefoil tolerates high Se and B in representative field soils and whether the species lowers Se and B concentrations in the soil.

PROCEDURES: A three year field study was established on Three Way Farms in the westside of the San Joaquin Valley, California. The treatment design was completely randomized design with each treatment replicated four times. Treatments consisted of 10 x 10 m plots planted to birdsfoot trefoil and (bare) control plots. Triplicate soil cores were collected within each plot from depths of 0-45 and 45-75 cm, respectively, prior to planting and at the beginning and end of each growing season for three years. The following are mean elemental concentrations (from soil solution extract) for all soil samples taken at preplant for 0-75 cm depth: 260 mg Ca L^{-1}, 76 mg Mg L^{-1}, 281 mg Na L^{-1}, 18 mg PO_4P L^{-1}, 729 mg SO_4S L^{-1}, 5 mMol Cl, Ec of 2.7 dSm^{-1}, pH of 7.8 and saturation water - percentage of 48. Birdsfoot trefoil above a height of 10 cm was clipped on average, every 55 d with a sickle-bar harvester. Subsamples were clipped from four 1 m^2 areas within each plot, dried, and weighed. Soil and plant concentrations of B and Se were determined using inductively coupled plasma spectrometry and by atomic absorption with continuous hydride generation after wet-acid digestion with HNO_3/H_2O_2. Irrigation scheduling was based on data acquired from the local California Irrigation System (CIMIS) weather station. The mean annual water applied by a sprinkler system was 845 mm, at a rate of about 10 mm hr^{-1}, while the mean annual rate of evaporation was about 1000 mm. Water used for irrigation contained negligible concentrations of both Se and B.

RESULTS: Birdsfoot trefoil tolerated the soil Se and B levels at the test plots without displaying any visual toxicities. High soil B levels did not significantly alter the yield in any of the test plots, which indicates a form of B tolerance exhibited by birdsfoot trefoil. The reduction of measurable soil Se and B was observed in all planted plots and to a lesser extent in bare plots (Table 1).

Table 1. Mean DM yield and clipped plant concentrations of Se and B in *Lotus corniculatus* grown 1990–1992*.

Year	Harvest	Dry matter yield (g/m^2)	Elemental concentrations:** Se (mg/kg DM)	B (mg/kg DM)
1990	1	350(35)[a]	0.42(0.03)[c]	86(6)[a]
	2	498(29)[b]	0.75(0.05)[e]	125(12)[b]
	3	576(20)[c]	0.87(0.06)[f]	132(10)[b]
1991	1	675(41)[d]	0.72(0.08)[e]	119(14)[b]
	2	592(26)[c]	0.46(0.06)[cd]	116(10)[b]
	3	595(36)[c]	0.37(0.05)[c]	118(12)[b]
1992	1	795(32)[e]	0.29(0.05)[b]	121(9)[b]
	2	715(16)[d]	0.29(0.04)[b]	112(8)[b]
	3	688(26)[d]	0.18(0.02)[a]	116(10)[b]

*Value presented represent means from all cropped plots followed by standard error of mean in parenthesis from a minimum of 16 separate samplings. Mean separation in columns obtained by Tukey's range test. The same letters represent no significant difference between yield and concentrations of both Se and B at the P = 0.05 level.

**For above-ground material; root concentration was 0.14 mg Se/kg DM and 110 mg B/kg DM.

Plant concentrations of Se and B are shown for each clipping including roots at harvest in Table 2. Shoot Se levels were correlated with preplant soil Se levels

(r=0.66, τ=0.44; P=0.01 level), while shoot B levels were also correlated with preplant extractable B levels (r=0.66, τ=0.46; P=0.01 level).

Table 2. Mean preplant and postharvest soil concentrations of total Se and extractable B between 0 to 75 cm during 1990–1992.

Year	Treatment	Total soil Se Preplant (mg/kg soil)	Total soil Se Harvest (mg/kg soil)	Extractable soil B Preplant (mg/L)	Extractable soil B Harvest (mg/L)
1990	bare	1.25(0.19)	1.09(0.11)[d]	9.29(0.13)	8.49(0.10)[d]
	cropped	1.25(0.19)	0.90(0.07)[c]	9.29(0.13)	7.47(0.11)[c]
1991	bare	1.01(0.14)	0.94(0.13)[c]	8.01(0.09)	7.78(0.12)[c]
	cropped	0.79(0.06)	0.70(0.06)[b]	7.02(0.10)	6.09(0.09)[b]
1992	bare	0.92(0.12)	0.89(0.12)[c]	7.49(0.13)	7.37(0.12)[c]
	cropped	0.64(0.08)	0.54(0.06)[a]	5.72(0.09)	4.98(0.08)[a]

*Values represent the mean from a minimum of 36 samples taken from four plots followed by the standard error of mean in parenthesis.
**Mean separation in columns obtained by Tukey's range test. The same letters represent no significant difference between change in soil Se and B from preplant to harvest of birdsfoot trefoil at the P = 0.05 level.

FUTURE PLANS: Continue planting birdsfoot trefoil on larger field plots contaminated with high levels of soil Se and B. Harvested plant material will be used for animal forage. Future testing would include monitoring Se content in animal blood. A manuscript will be prepared and submitted.

TRACE ELEMENT COMPOSITION OF *ATRIPLEX* IRRIGATED WITH SALINE DRAINAGE WATER

C.M. Watson, G.S. Bañuelos, J.W. O'Leary, and J.J. Riley

OBJECTIVES: Evaluate trace elements concentrations of five *Atriplex* species irrigated with multiple applications of agricultural effluent over an extended period.

PROCEDURES: Subsurface agricultural drainage water from farmlands with drainage related problems located on the westside of the Sam Joaquin Valley, California, is typically high in salinity and often contains elevated levels of trace elements, particularly boron (B) and selenium (Se). Irrigating salt tolerant halophytes may increase the number of times water can be used for irrigation and reduce the volume of subsurface drainage water to be disposed. A multiple year field study was conducted at Westlake Farms, Stratford, California (located on the western side of the San Joaquin Valley) to evaluate the trace element concentrations of B, Se, iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), and sulphur (S) in different clippings of the following plant species: *Atriplex canescens, A. undulata, A. deserticola, A. nummularia*, and *A. polycarpa.* All species were planted on 0.25 ha plots with subsurface drain lines installed 1.8 m deep and 30 m apart. Plant species layout was designed to accommodate harvest equipment and to maintain species purity of the harvested bales. *Atriplex undula, A. deserticola*, and *A nummularia* were planted as three month old transplants and *A. canescens* and *A. polycarpa* by direct seeding. Twenty cm of low salinity water was applied during initial plant establishment, while 300 cm of drainage water was applied with an average quality of 17 dSm^{-1}, 5-10 mg L^{-1} B and Se of 0.15 mg L^{-1}. Stands were harvested using standard alfalfa hay harvesting and baling equipment. There were a total of four harvests. The data presented represent harvests 13.0, 16.7, and 27.0 months after planting (referred to as harvests 2, 3, and 4, respectively). For each harvest period, three or four bales representing each species were sampled using a modified hay core sampler tube. Sulfur (S), Fe, Zn, Mn, and Cu were analyzed according to AOAC methods, while Se and B were determined as described elsewhere (Ann. Rpt., 1993; *Comparison of Wet Acid Digestion by Microwave or Block Digestion on the Recovery of Se and B in Plant Samples*). Data were analyzed using ANOVA, and LSD was used for mean separations of each element among and within species.

RESULTS: The accumulation of tissue Se and B was similar in all the tested *Atriplex* species, but varied with harvest date (Table 1). All tested *Atriplex* species were apparently tolerant of high levels of salts and trace elements in effluent. Results of the other analyses show that the trace element composition of *Atriplex* species from this site would not significantly endanger the nutritional value of the forage if used as a one-third maximum blend in animal feeds. Because cropping conditions, salinity, and trace element levels present in the drainage water and soils vary within the western San Joaquin Valley, it is not possible to translate results from this specific farm site to other regions that reuse agricultural effluent. The hazards of long-term repeated applications of saline drainage water with regard to plant growth and elemental uptake need to be considered.

FUTURE PLANS: A manuscript is currently in press.

Table 1. Mean levels of boron (B), selenium (Se), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu) and sulfur (S) in *Atriplex* bale samples at three harvest periods. Averages represent mean values of samples on dry weight basis from regrowth harvests (harvests 2, 3 and 4).

Species	B (mg kg^{-1})	Se (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	S (mg kg^{-1})
A. canescens							
Harvest 2	88	0.3	381	69	33	7	9.4
Harvest 3	140	0.3	425	50	36	7	11.3
Harvest 4	150	1.0	428	60	38	3	10.5
Average conc. of regrowth	124	0.5	411	60	36	6	10.4
A. undulata							
Harvest 2	108	0.3	318	117	40	10	4.9
Harvest 3	119	0.4	332	44	37	7	8.2
Harvest 4	167	1.0	394	44	33	4	9.5
Average conc. of regrowth	130	0.5	348	69	36	7	7.5
A. deserticola							
Harvest 2	73	0.4	379	78	34	8	6.7
Harvest 3	108	0.3	389	39	36	7	9.9
Harvest 4	183	1.1	397	43	36	2	16.3
Average conc. of regrowth	120	0.6	389	53	35	6	10.9
A. nummularia							
Harvest 2	106	0.4	553	59	35	6	5.9
Harvest 3	133	0.5	313	32	25	4	9.8
Harvest 4	189	1.0	308	41	31	4	12.1
Average conc. of regrowth	143	0.6	391	44	30	5	9.3
A. polycarpa							
Harvest 2	87	0.5	352	93	42	8	8.8
Harvest 3	127	0.4	391	45	33	6	9.2
Harvest 4	192	0.8	459	71	41	4	11.9
Average conc. of regrowth	131	0.5	401	70	39	6	9.9
LSD (0.05)*	12	0.1	72	11	5	1	1.8
LSD (0.05)**	23	0.1	125	19	9	2	3.2

*For comparison of regrowth means among species.
**For comparison of regrowth within species.

EVALUATION OF THE MOBILITY AND THE ACCUMULATION OF TRACE ELEMENTS IN SOIL AND DIFFERENT PLANT SPECIES ENRICHED WITH BIOSOLIDS

G.S. Bañuelos, S. Zambrzuski, and S. Akohoue

OBJECTIVE: Identify the total and soluble trace elements in soil enriched with biosolids and evaluate their uptake into different plant species.

PROCEDURE: High concentrations of trace elements found in biosolids may become soluble and mobile in irrigated agricultural soils. Consequently, they can be absorbed by the crops or move downward in the soil profile. Greenhouse pot experiments were conducted to study the plant uptake of the following trace elements: aluminum, copper, manganese, zinc, cadmium, molybdenum, iron, selenium, boron, sodium, calcium, magnesium. *Brassica napus* (canola), *Festuca arundinacea* (tall fescue), *Medicago sativa* (alfalfa), *Gossypium hirsutum* var. GC 510 (cotton) were grown in 15 L pots, respectively, containing (Panoche fine-loamy, mixed [calcareous], Thermic typic torriorthents) enriched with 500 g dried biosolids (rate is equivalent to 27 tons acre^{-1}, a commonly applied rate). Plants were grown in a temperature-controlled greenhouse using a 24° and 18°C (day/ night) temperature regime with an average irradiance of 750-850 μmol m^{-2}s^{-1} from cool white fluorescent lamps for 12 h. Trays were placed under each pot to collect any leachate. The experimental design structure was randomized complete block with five treatments, three blocks, and eight pots per treatment in each block (total of 24 pots per treatment). Treatments consisted of each plant species growing in soil containing biosolids and the same species growing in soils without biosolids; "controls" were irrigated daily based on water losses by weight (evaporative and transpiration) for each respective treatment throughout the designated growing season. Ninety days after first emergence, Indian mustard, canola, and cotton were harvested, while tall fescue and alfalfa were first clipped 70 d after emergence, and clipped every 20 d to a height of 10 cm thereafter. Soil and plant samples were taken from each pot at postharvest and analyzed for the above elements after wet acid digestion of soils and dry ashing of plant material, respectively, by the inductively coupled plasma spectrometer. Selenium was analyzed by atomic absorption spectrophotometry with continuous hydride generation after $HNO_3/H_2O_2/HCl$ digestion.

RESULTS: Preliminary data are shown in Table 1. In comparison to the perennial crops, canola and cotton accumulated higher concentrations of most measured elements. None of the tested plant species exhibited any visual toxicity symptoms or decreases in dry matter yield (data not shown). The preliminary results indicate that tall fescue and oats could be safely utilized as animal forage, however, careful consideration to elemental concentrations should be given to leafy-type plant species, i.e., canola.

FUTURE PLANS: Complete soil analyses of water extractable and total elements at postharvest. Future greenhouse experiments will include evaluating plant uptake after applying different rates of biosolids with other plant species growing in different soil types. Information collected from greenhouse experiments will be used to determine ideal and nontoxic application rates of biosolids for specific plant species under field conditions.

Table 1. Concentrations of selected elements in above-ground tissue from different plant species grown in soil with or without the addition of biosolids.*

Treatment to soil	Plant species**	Ca	Mg	Na	Fe	Al	Zn	Cd	Cu	Cr	Co	Mo	B	Se
		(%)			(mg kg^{-1} DM)									
- biosolid	tall fescue	0.5	0.3	0.3	25	36	18	0.2	3	0	0.1	3	12	0.1
+ biosolid		1.2	0.8	0.4	43	51	23	0.4	4	0	0.2	5	25	0.2
- biosolid	canola	2.3	0.5	0.3	71	49	35	1	2	0	0	3	53	0.4
+ biosolid		3.3	0.5	0.4	115	72	100	5	7	0	0	6	45	1.5
- biosolid	oats	0.5	0.2	0.2	44	18	15	0.2	3	0.1	0.2	6	20	0.1
+ biosolid		0.6	0.2	0.3	55	21	18	0.2	4	0.1	0.2	6	23	0.2
- biosolid	cotton	3.3	0.6	0.2	167	230	62	4	3	0	0	4	52	0.3
+ biosolid		3.5	0.6	0.2	200	341	64	4	6	0	0	9	61	0.4

*Values presented represent the mean from ten replications.

**Values from tall fescue and oats represent the mean concentration from three different clippings.

BORON AND SELENIUM REMOVAL IN BORON-LADEN SOILS BY FOUR SPRINKLER-IRRIGATED PLANT SPECIES

G.S. Bañuelos, G. Cardon, B. Mackey, J. Ben-Asher, L. Wu, P. Beusilinck, S. Akohoue, S. Zambrzuski, R. Mead, S. Downey, and P. Samra

OBJECTIVE: To determine if four plant species lower water-extractable soil B and total soil Se concentrations after harvest.

PROCEDURES: A multiple year field study is being conducted on Three Way Farms near Los Baños, California. The field site had been previously planted to ornamental eucalyptus for at least three years prior to the current study. The soil was a Los Baños clay-loam, fine mixed thermic Typic Haploxeralfs. The treatment design was a completely randomized design with each treatment replicated a minimum of four times. Each plot was 10 by 10 m in size. Treatments consisted of plantings of the following: *Brassica juncea* (Indian mustard), *Festuca arundinacae* (tall fescue), *Lotus corniculatus* (birdsfoot trefoil), *Hibiscus cannabinus* (kenaf), and bare plots (no plants). Plant species were planted to the following densities within each plot: Indian mustard with 20 cm spacing - 25 plants m^{-2}, tall fescue and birdsfoot trefoil with 20 cm spacing - 125-150 plants m^{-2}, and kenaf 20 cm spacing - 50 plants m^{-2}. Bare plots were kept weed free. Prior to planting, access tubes were installed to 1.7 m in depth in each of the plots, and four soil cores were collected within each plot from depth intervals of 0-45 cm and 45-75 cm, respectively. Two core samples from both the southern and northern half of each plot were composited for each depth interval to give a total of two soil samples at each depth in all plots. At final harvest, soil samples were taken at the same location in the same manner described above. Irrigation scheduling was based in part on the local CIMIS and weekly neutron probe readings. Total water applied by a sprinkler system was 800 mm (1st year) and 890 mm (2nd year) at a rate of about 10 mm h^{-1}. Irrigation water contained negligible concentrations of both B and Se (<10 $\mu g\ L^{-1}$). Tall fescue and birdsfoot trefoil were each hand-clipped at 78, 103, and 133 d after emergence, while Indian mustard was harvested 90 d after emergence and kenaf 115 d. After each clipping or harvest, plants were separated into leaves, stalks, and when applicable, roots. Both plant and soil samples were prepared as described elsewhere (Ann. Rpt. 1993: *Comparison of Wet Acid digestion by Microwave or Block Digestion on the Recovery of Se and B in Plant Samples*) and tissue B and extractable B were analyzed spectrophotometrically after wet acid digestion and from saturated soil extract, respectively. Total Se tissue was analyzed by atomic absorption with continuous hydride generation.

RESULTS: Kenaf had the highest concentration of tissue B and Indian mustard had the highest concentration of tissue Se among the plant species, irrespective of the year of the study (Table 1). When considering the shoot B data for all species, shoot B concentrations were correlated with preplant-extractable soil B levels ($r=0.66$ and $\tau=0.46$; $P=0.01$ level) and postharvest soil B levels ($r=0.64$ and $\tau=0.45$; $P=0.01$ level). Shoot Se concentrations from all species were correlated with preplant soil Se levels ($r=0.60$ and $\tau=0.44$; $P=0.01$ level). Extractable soil B levels were all lower by at least 24% after final harvest of each species (Table 2). Extractable B reductions in cropped plots were greater than bare plots at the $P=0.01$ level. Cropped plots, especially that of Indian mustard, had reductions of total soil Se greater than zero at $P=0.05$ level, while soils from bare plots were not different from zero (Table 2).

FUTURE PLANS: Plant tall fescue in the plots in which B and Se soil levels have been lowered. Future crop rotation in the same plots will include one or more of the tested plant species. A manuscript has been submitted.

Table 1. Mean dry matter yield and tissue concentrations of boron and selenium in crops grown in 1990 and 1991 experiments.

Species	Harvest	Dry Matter Yield (gm^{-2})	B Concentrations in: Shoot (mg kg^{-1} DM)	B Concentrations in: Root (mg kg^{-1} DM)	Se Concentrations in: Shoot (µg kg^{-1} DM)	Se Concentrations in: Root (µg kg^{-1} DM)
1990 Experiment†‡§						
Indian mustard	I	1258(124)c	112(14)a	—	950(80)cd	—
Tall fescue¶	I	347(58)b	58(11)a	—	310(60)a	—
Tall fescue	II	100(43)a	108(18)b	—	630(40)b	—
Birdsfoot trefoil	I	173(36)a	84(6)ab	—	440(30)a	—
Birdsfoot trefoil	II	450(25)b	131(12)b	—	870(90)c	—
1991 Experiment						
Indian mustard	I	995(66)d	224(16)b	112(7)a	1050(50)d	780(20)c
Tall fescue	I	477(31)b	86(11)a	—	170(10)a	—
Tall fescue	II	203(23)a	101(16)a	—	200(20)a	—
Tall fescue	III	225(20)a	101(11)a	108(13)a	270(20)b	130(10)a
Birdsfoot trefoil	I	515(41)b	116(11)a	—	360(60)bc	—
Birdsfoot trefoil	II	562(36)b	116(6)a	—	290(40)bc	—
Birdsfoot trefoil	III	675(29)c	118(8)a	110(9)a	220(30)b	140(10)a
Kenaf	I	2655(167)e	685(111)c	131(7)a	520(40)c	420(40)b

†Values presented represent means followed by standard error of mean in parenthesis from a minimum of 20 separate samplings in 1990 and 12 samplings in 1991.
Mean separation in columns within years obtained by Tukey's range test (with standard error of mean in parenthesis). The same letters represent no significant difference between species or clipping at the P=0.05 level.

‡Root samples were not taken.

§Perennial crops were clipped only two times.

¶Limited data (see text); dry matter yield not included in statisical analyses.

Table 2. Mean preplant and postharvest soil concentrations of total B and Se and extractable B between 0–60 cm for 1990 and 1991 experiments.

Species	Total Soil B at: Preplant (mg kg^{-1} soil)	Total Soil B at: Harvest (mg kg^{-1} soil)	Extractable B at: Preplant (mg L^{-1})	Extractable B at: Harvest (mg L^{-1})	Total Soil Se at: Preplant (mg kg^{-1} soil)	Total Soil Se at: Harvest (mg kg^{-1} soil)
1990 Experiment†‡						
Control (bare plot)	58.1(0.36)	56.3(0.41)a§	4.47(0.52)	3.99(0.66)a	0.49(0.11)	0.43(0.01)a
Indian mustard	53.2(0.47)	47.6(0.52)b	4.91(0.66)	2.10(0.43)b	0.50(0.10)	0.10(0.43)b
Tall fescue	56.3(0.53)	50.2(0.64)b	5.55(0.62)	2.54(0.46)b	0.46(0.10)	0.24(0.06)b
Birdsfoot trefoil	52.2(0.63)	46.6(0.52)b	5.14(0.57)	2.26(0.38)b	0.39(0.10)	0.12(0.07)b
1991 Experiment¶						
Control (bare plot)	51.2(0.49)	49.7(0.59)a	3.57(0.60)	3.43(0.11)b	0.88(0.05)	0.86(0.02)a
Indian mustard	49.3(0.65)	45.7(0.59)b	3.68(0.65)	2.52(0.22)b	0.86(0.04)	0.63(0.02)b
Tall fescue	52.1(0.57)	49.1(0.60)a	2.88(0.67)	2.13(0.23)b	0.65(0.06)	0.55(0.03)b
Birdsfoot trefoil	48.0(0.60)	43.3(0.70)b	4.16(0.71)	2.98(0.22)b	0.82(0.08)	0.71(0.03)b
Kenaf	45.5(0.59)	40.6(0.63)b	4.65(0.82)	3.44(0.23)b	0.75(0.06)	0.61(0.01)b

†Values represent the mean from 36 soil samples followed by the standard error of mean in parenthesis.
‡Kenaf was not planted in 1990.
§Mean separation in columns obtained by Tukey's range test. The same letters represent no significant difference between change in soil B and Se from preplant to harvest for given treatments at the P=0.05 level species at the P=0.05 level.
¶Values represent the mean from 16 soil samples followed by the standard error of mean in parenthesis.

SUPPORT LABORATORIES

ANALYTICAL CHEMISTRY LABORATORY

T.J. Pflaum, C.A. Ament, G.S. Bañuelos, and G.M. Rajashekar

The main purpose of the Analytical Chemistry Laboratory is to support field research projects for the Water Management Research Laboratory. The types of samples analyzed include soils, water, and plant tissue. The total number of analyses performed for 1993 was 47,400. The total number of all samples was 6,200.

During the year of 1993, 35,400 analyses for cations and anions were performed on a total of 3,900 soil samples. In addition to the soil samples, 900 water and 1,400 plant tissue samples were examined for a total of 7,600 and 4,400 analyses, respectively.

The implementation of safety regulations regarding respirator equipment and the necessity for physical examinations has limited the number of technicians who are able to grind plant and soil samples.

There have been changes in the laboratory equipment:

The lab has purchased 1440 new cans for soil sampling. The old soil cans and the new cans are now stored in the outside trailer.

The Thermo Jarrell Ash AA Spectrophotometer has difficulty when operating in double beam mode. The best solution is to operate the AA in single beam mode. During a service call, the calibration and operation of the AA was checked.

The Perkin Elmer ICP was calibrated and its operation checked during a service call.

A new spectrophotometer was purchased from Milton Roy since the old unit had to be returned to Milton Roy for major repairs.

ELECTRONICS ENGINEERING LABORATORY

D. Clark, M. Norman, A. Neverez

The Electronics Engineering Laboratory provides electronic and computer services in support of research projects. Currently there are sixteen remotely located data acquisition systems including twelve irrigation control systems. The electronics laboratory is responsible for the operation, maintenance, data collection, and processing of these systems, as well as the design, programming, and installation of new or modified systems. The year's work included the following.

At Brawley, three lightbars and a pyranometer were added to the lysimeter system. New voltage references were built for the soil moisture sensors, and the four dataloggers were reinstalled in field F3. Fertilizer controls were installed on the manifold system for both fields.

At the West Side Field Station, the installation and programming of the 36 plots system was completed. A new irrigation control system for the north lysimeter field was started. This system is operational but is not finished. Programming and installation of a moisture sensor system for the north field was completed. Data reports were set up for the 36 plots and moisture sensor projects.

At Shafter, the irrigation control system was redesigned and reprogrammed to include an additional three treatment crop. The installation was modified for the new crop and an additional data report was set up.

The program for the grape lysimeter at Kearney was rewritten to allow more flexible control of the irrigation treatments. Work was started on a new irrigation project at the 30 acres. The Harris Project came to an end, and the evaporation pan and datalogger system were removed from the field.

The batch programs and documentation for the automated data collection and processing system were improved. Work was started to simplify and structure the macro programs to make them more flexible and easier to work with.

Other work involved upgrading the dataloggers at the West Side Field Station, Kearney, and Shafter; lysimeter repairs at the West side Field station and Kearney; routine maintenance and calibration of field systems; and miscellaneous data processing.

RESEARCH SHOP

David Dettinger

The research shop provides machine shop service for the field projects at Water Management Research Laboratory. Equipment maintenance, repairs and modifications are all performed in the new facility at the Fresno location. Water Management Research Laboratory has a growing inventory of agricultural equipment that must be maintained and transported to the research sites.

Building research equipment is another function of the shop. The main ongoing project this past year has been the construction of two large weighing lysimeters. The two halves of the lysimeters were backfilled, stacked up and welded together. Holes were bored into the core and access tubes installed for instrumentation. The scales were assembled in the new underground housing and the lysimeters were set in place.

Some time was spent organizing the new shop building with special attention to safety. Student help was provided in the summer and a graduate student helped install tubes, sandblast, paint and put the scales together.

PUBLIATIONS

MANUSCRIPTS PUBLISHED IN 1993

Hutmacher, R.B., C.J. Phene, K.R. Davis, T.A. Kerby. 1993. Acala and Pima cotton responses to subsurface drip irrigation: Water use, plant water relations, yield. *Proceedings, Beltwide Cotton Conference, New Orleans, LA, January 11-14, 3:1221-1224.*

DeTar, W.R., C.J. Phene, D.A. Clark, T.A. Kerby. 1993. Comparison of water use and yields of Acala and Pima cottons for subsurface drip vs. furrow irrigation. *Proceedings, Beltwide Cotton Conference, New Orleans, LA, January 11-14, 1:540-541.*

Marani, A., R.B. Hutmacher and C.J. Phene. 1993. Validation of CALGOS simulation of leaf water potential in drip-irrigated cotton. *Proceedings, Beltwide Cotton Conference, New Orleans, LA, January 11-14, 3:1225-1228.*

Phene, C.J., R.B. Hutmacher, K.R. Davis, S.S. Vail, T.J. Pflaum. 1993. Effects of irrigation management and mineral nutrition on productivity of tomatoes. *Tomato News, pp. 18-29, January 1993.*

Bañuelos, G.S., R.M. Mead, and G.J. Hoffman. 1993. Accumulation of selenium in wild mustard irrigated with agricultural effluent. *Agriculture, Ecosystems and Environment, 43:119-126.*

Vogt, W. 1993. ARTICLE. Drip-Irrigated Alfalfa: Higher Yields, Less Water. *Hay and Forage Grower, pp. 26, 31, March 1993.*

Marani, A. and C.J. Phene. 1993. Simulation of reference evapotranspiration in arid regions. *Summary Presentation, Crop Simulation Workshop, Phoenix, AZ, April 1993.*

Phene, C.J., K.R. Davis, R.B. Hutmacher, R.M. Mead, J.E. Ayars and R.A. Schoneman. 1993. Maximizing Water-Use Efficiency with Subsurface Drip Irrigation. *Irrigation Journal, pp. 8, 11-13, April 1993.*

Bañuelos, G.S., G.E. Cardon, C.J. Phene, L. Wu, S. Akohoue and S. Zambrzuski. 1993. Soil boron and selenium removal by three plant species. *Plant and Soil, 148:253-263.*

Cardon, G.E., C.J. Phene, D.A. Clark. 1993. Soil matric potential sensor calibration: Physical equipment and statistical data processing methods. *Applied Engineering in Agriculture, 9(2):213-219, March 1993.*

Ben-Asher, J. and C.J. Phene. 1993. The effect of surface drip irrigation on soil water regime evaporation and transpiration. *Proceedings, 6th International Conference on Irrigation, Tel-Aviv, Israel, 3-4 May, pp. 35-42.*

Phene, C.J., R.B. Hutmacher, J.E. Ayars and J. Ben-Asher. 1993. Subsurface drip irrigation, a BMP for controlling drainage outflow and reducing groundwater contamination, pp. 51-69 *IN:* Y. Eckstein and A. Zaporozec (eds.), *Industrial and Agricultural Impacts on the Hydrologic Environment, American Institute of Hydrology Water Environment Federation, Alexandria, VA.*

Ayars, J.E., R.B. Hutmacher, C.J. Phene and R.A. Schoneman. 1993. Managing irrigation in the presence of groundwater. *Proceedings, Management of Irrigation and Drainage Systems, Irrigation and Drainage Div./ASCE, Park City, UT, July 21-23, pp. 723-730.*

Bañuelos, G.S., S. Akohoue, S. Zambrzuski, S. Downey, R. Mead, M. Bhangoo. 1993. Boron and selenium removal in boron-laden soils by kenaf. *Proceedings, 1993 International Kenaf Conference, Fresno, CA, March 3-5, pp. 84-91.*

Bañuelos, G.S. 1993. Bio-remediation of seleniferous soils in Central California with selenium accumulator crops. *Trilateral Faculty Exchange Seminar, "Food Systems and the Environment", Fresno, CA, August 10-11, pp. 219-230.*

Phene, C.J., D.A. Bucks, R.B. Hutmacher, J.E. Ayars. 1993. Research successes, applications and needs of subsurface drip irrigation. *IN:* Workshop on Micro Irrigation Worldwide, pp. 249-267. *Proceedings, 15th Congress on Irrigation and Drainage, ICID-CIID, La Hague, Netherlands, 30 August-11 September.*

Ayars, J.E., R.B. Hutmacher. 1993. Soil salinity under micro-irrigation with saline water. *IN:* Workshop on Micro Irrigation Worldwide, pp. 233-245. *Proceedings, 15th Congress on Irrigation and Drainage, ICID-CIID, La Hague, Netherlands, 30 August-11 September.*

Oster, J.D., R.B. Smith, C. Phene, A. Fulton, S.W. Styles, and T. Fernandes. 1993. Irrigation Methods for Drainage Reduction: Subsurface Drip vs. Furrow Irrigation. *Proceedings, 15th Congress on Irrigation and Drainage, ICID-CIID, La Hague, Netherlands, 30 August-11 September, Volume 1-C, R.85, pp. 1083-1095.*

Bañuelos, G.S., L. Wu, S. Akohoue, S. Zambrzuski, and R. Mead. 1993. Trace element composition of different plant species used for remediation of boron-laden soils. *IN:* N.J. Barrow (Ed.), Plant Nutrition - from Genetic Engineering to Field Practice, pp. 425-428. *Proceedings of the Twelfth International Plant Nutrition Colloquium, 21-26 September, Perth, Western Australia. Kluwer Academic Publishers, Dordrecht/Boston/Lancaster.*

Wood, M. 1993. ARTICLE. Will Salty Water Sabotage Almonds? *Agricultural Research, 41(7):20-21, July 1993.*

Marani, A., C.J. Phene. 1993. ABSTRACT. CALGOS - a model of irrigated cotton. *Agronomy Abstracts, 1993 Annual Meetings, Cincinnati, OH, November 7-12, p. 71.*

Hutmacher, R.B., C.J. Phene, K.R. Davis, T.A. Kerby, S.S. Vail. 1993. ABSTRACT. Cotton responses to deficit subsurface drip irrigation. *Agronomy Abstracts, 1993 Annual Meetings, Cincinnati, OH, November 7-12, p. 114.*

Phene, C.J. 1993. Subsurface drip irrigation on row crops. *Proceedings, Micro-irrigation Workshop and Trade Show, Santa Maria, CA, October 21, pp. 14-32.*

McGill, S., R.B. Hutmacher. 1993. ARTICLE. Buried Drip for Alfalfa? *The Furrow, 98(7):26-27, November-December 1993.*

Bañuelos, G.S., D. Dyer, R. Ahmad, S. Ismail, R.N. Raut, J.C. Dagar. 1993. In search of *Brassica* germplasm in saline semi-arid and arid regions of India and Pakistan for bioremediation of selenium laden soils. *Journal of Soil and Water Conservation, 48(6):530-534, November/December 1993.*

Bañuelos, G.S., S. Akohoue, S. Zambrzuski, G. Cardon, B. Mackey, J. Ben-Asher, L. Wu, P. Beuselinck. 1993. Boron and selenium removal in boron-laden soils by four sprinkler irrigated plant species. *Journal of Environmental Quality, 22(4):786-792, October-December 1993.*

Ayars, J.E., R.B. Hutmacher, R.A. Schoneman, S.S. Vail, T. Pflaum. 1993. Long term use of saline water for irrigation. *Irrigation Science, 14(1):27-34.*

Phene, C.J., K.R. Davis, R.M. Mead, R. Yue, I-Pai Wu, R.B. Hutmacher. 1993. Evaluation of a subsurface drip irrigation system after ten cropping seasons. *Presentation, ASAE Paper No. 93-2560, 19 pp., Chicago, IL, December 14-17.*

Catlin, P.B., G.J. Hoffman, R.M. Mead, R.S. Johnson. 1993. Long-term response of mature plum trees to salinity. *Irrigation Science, 13:171-176.*

Williams, L.E., D.W. Grimes, W.L. Peacock, C.J. Phene. 1993. Water use of grapevines measured by weighing lysimetry: Effect of trellis type. *1993 Annual report to the California Table Grape Commission and the California Raisin Advisory Board.*

ACCEPTED FOR PUBLICATION IN 1994

Ayars, J.E., R.M. Mead, I.C. Paltineanu, J. Liu. 1994. Radioactive versus capacitance techniques for measuring soil moisture. *(Proceedings, Intern'l Symp. on Nuclear and Related Techniques in Soil/Plant Studies on Sustain- able Agriculture and Environmental Preservation, Vienna, Austria, October 17–21)*

Ayars, J.E., D. Wichelns, D. Cone. 1994. Water management principles for drainage reduction and a case study of the Broadview Water District. *(Proceedings, AAAS Symposium, Toxic Trace Elements and Sustainability in Agroecosystems, San Francisco, CA, Jun 19–23)*

Bañuelos, G.S., B. Mackey, L. Wu, S. Zambrzuski and S. Akohoue. 1994. Bioextraction of soil boron by tall fescue. *(Journal of Ecoloxicology and Environmental Safety)*

Bañuelos, G.S., B. Mackey, C. Cook, S. Akohoue, S. Zambrzuski, and P. Samra. 1994. Growing cotton and kenaf with Boron-laden water and soil. *(Plant Soil)*

Jayaweera, G., T. Tokunaga, W.T. Frankenberger, N. Terry, G.S. Bañuelos. 1994. Selenium remediation in soils, sediments, and waters. *(Proceedings Chapter, AAAS Symposium, Toxic Trace Elements, Sustainability in Agroecosystems, San Francisco, CA, June 19–23)*

Phene, C.J., R.B. Hutmacher, J.E. Ayars. 1994. Subsurface drip irrigation in the USA. *(Proceedings, Workshop on Sprinkler and Drip Irrigation Systems, Jalgaon, India, December 8–10)*